A DRIVING SIMULATOR METHODOLOGY FOR EVALUATING ENHANCED MOTORCYCLE CONSPICUITY

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ABSTRACT

A methodology was developed for evaluating enhanced powered two wheeler (PTW) conspicuity in a driving simulator environment. In order to evaluate the methodology, a driving simulator experiment was conducted involving n = 10 European car drivers. Testing involved full-task, "blind" experiments in which the driver subjects did not know the true purpose of the experiment, which was to measure differences in behavior due to various PTW frontal lighting treatments. Realistic driving was performed in urban and rural conditions, with drivers performing various realistic primary and secondary driving tasks. Drivers navigated a road circuit that included several real PTW accident sites and scenarios from MAIDS (Motorcycle Accidents In Depth Study) that were accurately modeled in the driving simulator. The lighting treatments included the baseline PTW lighting treatment, which was a single dipped-beam headlamp of a typical sport motorcycle, and three hypothetical lighting treatment examples. The effects of car daytime running lamps were also evaluated, with either 10 or 90% of cars operating with headlights on. The following parameters were measured: detection distance of opposing vehicle (OV), decision as to whether to turn in front of OV, and minimum distance to OV. From these data, the probability of collision with an OV was calculated. Based on this, the potential reduction in the overall number of accidents was estimated based on the subjective relevance of the experimental findings to each of 129 accident configurations in the MAIDS database. In addition, the driving simulator was validated by performing a vehicle detection task in both simulator and full-scale environments. The validation tests indicated similar motorcycle detection rates between the simulator and the full-scale environments. Overall, the simulator methodology was found to provide a powerful tool for researching differences in driver behaviour and collision probability due to daytime lighting treatments in this sample of real accident scenarios.

INTRODUCTION

Background

The current study comprises one part of ACEM's overall safety programme, which is aimed at improving powered two wheeler (PTW) active safety (i.e., accident avoidance). This programme is based on increasing the understanding of how and why PTW accidents occur, in particular by means of the recent "Motorcycle Accidents In Depth Study" (MAIDS) of n = 921 accidents in 5 EU countries (ACEM, 2004).

The topic of PTW conspicuity as a strategic means for improving PTW safety had been identified by ACEM during MAIDS and in previous years, by reference to several findings:

- The relatively high frequency at which "Other vehicle (OV) driver perception failures" had been identified in PTW in-depth accident research (e.g., Hurt et al., 1981; Vis, 1995; ACEM, 2004);
- Prior research indicating that many vulnerable road users (e.g., pedestrians, bicyclists and PTWs) have relatively low conspicuity in traffic due to their small sizes and relatively low exposure frequencies;
- Increasing, and possible future mandatory, use of specialized daytime running lights on cars (e.g., as indicated in ECE R87, with amendments);

- Worldwide harmonization of lighting regulations (e.g., as in ECE/WP29/GRE), including discussions of PTW amber position lights, among other topics.

Together, these have led to ACEM's current policy in regard to enhancement of PTW conspicuity. Namely, the first step: automatic headlamp on (AHO); second step: research of enhanced PTW conspicuity; third (more long term) step: use of ITS/Telematics. It is on one part of the second step of these that the current paper is focused.

Objectives

Against the background in Europe of the overall objective of reducing road casualties, accidents between cars and powered two wheelers (PTWs) are being studied. PTWs are expected to be increasingly operating in a car daytime running light (DRL) and PTW automatic headlamp-on (AHO) environment, and many stakeholders are considering further increases in the conspicuity of PTW lighting systems.

The objective of the work reported in this paper was to develop a methodology that was capable of scientifically measuring increases in active (i.e., sensory, visual performance, photometric) and passive (i.e., behavioural, task performance, cognitive) conspicuity in realistic traffic, lighting and accident scenarios.

Previous Accident Research

There have been several in-depth accident investigations culminating with the recent MAIDS report (ACEM, 2004), which have helped to identify "primary contributing factors" in PTW accidents. Several examples are mentioned here that provide impetus to this study on PTW conspicuity.

Table 1 gives a distribution of which vehicle had priority in n = 259 PTW accidents in the Netherlands (NL) reported by Vis (1995). This data suggests that the PTW had priority in the great majority of cases (211 of 259 cases, or 81%).

Table 1.
Priority by road user (Vis, 1995)

Priority by:	Sign / Rule	Traffic Lights
PTW	190	21
Car	18	14
Unknown	7	9
Total	215	44

Table 2 lists the collision avoidance action of PTWs and cars in these same accidents. As can be seen, in 72% of the cases the car driver took no evasive action before the PTW was struck. This suggests several possible contributing factors: a lack of driver perception of the PTW, improper speed-distance perception, or disregard for PTWs. It is important to attempt to further clarify the relative frequencies of these different mechanisms in order to devise suitable countermeasures, and this was a goal of the current research.

Table 2.
Collision avoidance action (Vis, 1995)

	PTW	Car
Nothing	26%	72%
Braking	51%	17%
Steering	12%	5%
Accelerating	2%	1%
Other	9%	5%
Total	100%	100%

Table 3 indicates the distribution of whether the car driver or PTW rider saw the other party prior to the crash, in the same NL study. The drivers reported that in 50% of cases they did not see the PTW, and in 20% of cases that they saw the PTW "too late" (versus 5% and 20% for the PTW rider, respectively). The same data indicate that the PTW rider saw the car in 70% of cases, but the driver saw the PTW in only 25% of cases.

Table 3.
Did you see the other party? (Vis, 1995)

	PTW	Car
Yes	70%	25%
But, too late	20%	20%
Not at all	5%	50%
Unknown	5%	5%
Total	100%	100%

Table 4 summarizes the frequency of various PTW accident conditions for the two larger in-depth PTW "regional census" studies (Hurt et al., 1981; ACEM, 2004). These are two of the best-known in-depth investigations of motorcycle accidents. The data from both studies indicate that the majority of accidents occurred in daylight (75 and 73%, respectively); clear weather (84 and 90%); involved two-vehicle collisions (75 and 80%); with an "other vehicle" bearing from the PTW of 11 to 1 o'clock (77 and 71%); and light to moderate traffic (85 and 85%). In addition, the Hurt data indicated that the other vehicle violated the PTW priority in 51% of cases and the PTW was considered to have "low" or "no" conspicuity in 46% of cases.

Table 4.
Accident conditions (Hurt, 1981; ACEM, 2004)

Accident Condition	% of all PTW accidents: Hurt et al. (n=900)	% of all PTW accidents: ACEM (n=921)
Daylight	75	73
Clear weather	84	90
Two-vehicle collision (MC-OV)	75	80
Other vehicle (OV) violates PTW priority	51	NR
PTW “low” or “no” [sensory] conspicuity	46	NR
OV “low” or “no” [sensory] conspicuity	5	NR
Bearing of OV from PTW, 11 to 1 o’clock	77	71
Light or moderate traffic, no congestion	85	86
Headlamp off (daylight)	51	moped: 41 MC: 11

NR = Not reported

The two-vehicle (MC-OV) collision was the largest category of collision type, as noted in Table 4. Within the two-vehicle collision category, the highest percentage of collisions was due to "other vehicle driver perception failures" (n = 337 or 37% of all accidents from MAIDS). Other relevant types of two-vehicle PTW accidents within and outside this category include: OV turning in front of PTW from perpendicular path (n = 57 or 6%); PTW background or clothing contributed to lack of conspicuity (n = 35 or 4%); OV/MC paths perpendicular (n = 60 or 7%); and MC/OV traveling in opposite directions (n = 73 or 8%). In addition, other conspicuity-related accident types as coded by the investigators included "driver comprehension failures" (n = 13 or 1%) such as speed-distance misjudgment; other driver decision failures (n = 91 or 10%) which involve improper judgment of PTW collision threat; and partial, moving or complete view obstructions (n = 31 or 3%) where low PTW conspicuity (as it re-appeared) may have worsened the outcome. Together, these conspicuity-related accident typologies form a very sizeable fraction (i.e., the majority) of PTW accidents.

Conspicuity Research and Applications

A comprehensive review of daytime running lights was provided by Rumar (2003). Overall, the review indicates a rapidly increasing trend toward "daytime lighting" on both cars and PTWs in Europe as well as in other regions.

For cars, a standard for universal daytime running lights has been proposed, and implementation plans are considering "automatic dipped beams-on" versus "dedicated DRL's" in the mid-term, and "adaptive lighting systems" in the longer term.

For PTWs, ACEM members already equip PTWs with "automatic headlamp-on" (AHO). In addition, riders are required to use headlamps during daytime in Denmark, Spain, France, Germany, Italy, Lithuania, Poland, Sweden and Finland.

A typical PTW asymmetric beam pattern that meets ECE R20 (today R112) provides high illumination in nighttime, mostly in below horizontal, forward-road zones. The illuminance at the opposing driver's eye point (DEP: located at the eye of the driver in a car at 25 m distance in the opposing lane) is required to be less than 0.4 lux. However, there are several important considerations surrounding this fact. First, there is a wide variation in the market of illuminance values at the DEP (usually far below the maximum), and also in the areas surrounding this point (because they are unregulated). Second, this zone is of primary importance for "daytime conspicuity" of the PTW to the opposing driver. Third, the legal maximum intensity for dipped beams at the DEP is far below the minimum recommended by Rumar (2003) for daytime lighting. This means that dipped beams, which are designed for nighttime, may not be optimal for daytime conspicuity improvement applications.

The vehicle lighting industry has reported in numerous publications that current and new technology provides many solutions for "dedicated DRLs" for cars which are designed to be visible at the DEP, and which are not required to project very great levels of illumination on the roadway at night. For this reason, such "dedicated DRLs" are claimed to have advantages of very low energy consumption, low cost, as well as flexible packaging alternatives. At the time of initiation of this study there were no production dedicated DRLs in the EU market.

Most prior research on PTW conspicuity has focused on various treatments for the PTW and the rider, often with limited or greatly simplified methodologies and unclear or conflicting findings. Since rider preferences for clothing and helmet colour should not be standardized or regulated, it may be more feasible to focus on enhancement of conspicuity (and in particular in daytime lighting) improvements for the PTW itself. Due to the relatively high frequency of "11 to 1 o'clock" opposing vehicle "bearings" in PTW accidents, the most promising area for PTW treatment enhancement may be in forward directions, which could consist of a combination of headlamps, position lamps and running lamps, or any other technology that would improve PTW perception and conspicuity. These lighting treatments have numerous characteristics that could be varied including size, number, location, intensity, and colour and possibly modulation rate and level, in order to determine the most effective combinations.

Past research has been done regarding the behaviour of typical car drivers interacting with PTWs in hypothetical or laboratory conditions. Understanding the behaviour of the opposing driver in real traffic situations helps guide efforts for increasing PTW conspicuity. Therefore, placing drivers in realistic potential accident situations using simulated PTWs can help to better define the problem from the perspective of driver behaviour.

Driving simulator experiments have been recommended by various researchers to be the most desirable means to study PTW conspicuity. The simulator can be used to re-create accident situations for comparison with the real-world situations. The simulator allows these accident re-creations to depict real accident situations, a feature that full-scale testing cannot provide. The high levels of experimental control and repeatability of the simulator environment are also key benefits. A naturalistic, blind driving experiment can be readily performed in a simulator with no risk to the driver subject and can involve real life distractions and workload. The conspicuity (enhancing) technologies can be (photometrically) calibrated to match the real world, and validation can be made against full-scale PTW detection tests. Simulator tests are safer, and also typically require fewer research team members to participate in the testing. Finally, the human and vehicle input and output variables are more easily measured in driving simulators.

METHODOLOGY

Driving Simulator

All pilot testing and main testing was performed in the Dynamic Research, Inc. (DRI) moving-base Driving Simulator. The Driving Simulator is a research grade, dynamically realistic, moving base, "driver-in-the-loop" device. The application takes advantage of the experimental control, flexibility, measurement ease and safety that are provided thereby.

Driver subjects sat in a vehicle cab equipped with instrumented controls and displays. The vehicle dynamic model used in the simulator for these experiments was a BMW 3-series car with automatic transmission, which had been used routinely in previous driver/vehicle response and performance studies. The driver interactively applied all steering, braking, and throttle actions needed to control the vehicle. The Driving Simulator utilized complex high texture computer-generated roadway scenes, which were displayed on a 180-degree forward field-of-view in front of the driver, projected to display the view from the driver's eye point. The roadway graphics consisted of photographically realistic, texture-mapped images and suitably calibrated ambient and vehicle lighting. Buildings and other objects used digital photographic images that were "wallpapered" onto 3D polygons. An ambient (solar) lighting model was used and standardized to be representative of typical motorcycle operating conditions in Europe. Simulator motion was provided by a 6 degree-of-freedom hexapod motion system. A synthesizer generated traffic noise, including the Doppler effect, in order to be as realistic as possible. A research assistant was present in the cab with the driver subject at all times.

All driver and vehicle motion and control measures were recorded for data analysis. The simulator has the capability to measure and record virtually all motion and control states. The driver's line-of-sight in the visual field was also recorded, by means of an ISCAN eye tracking system (Razdan et al., 1988).

Road Circuit

The road circuit used for this study consisted of a total of 5 intersections from the MAIDS accident database, each presented two times during one lap, in different orders. The 5 sampled cases were those in which combinations of conspicuity factors were identified by the MAIDS investigation teams. These were: "Opposing vehicle driver perception failure" plus "motorcycle background or rider clothing contribution to lack of conspicuity."

The road circuit, shown in Fig 1, was about 7 kilometers in length. Two-lane roads connected each of the intersections (one lane in each direction).

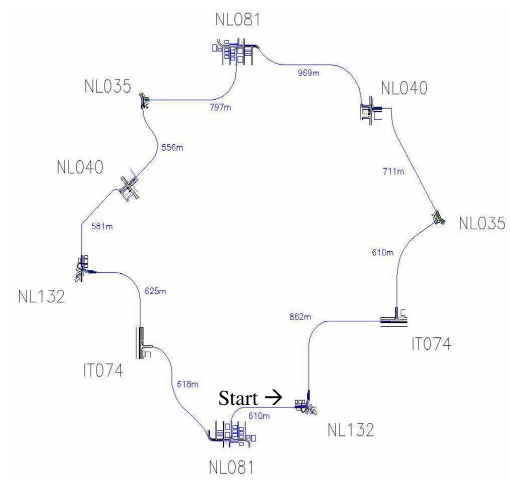

Figure 1. Simulator road circuit.

Accident Scenarios

At each of the intersections, and based on the conditions coded by the accident investigation teams, several vehicles were situated and moving such that the subject vehicle would be presented with a random-appearing but exactly repeatable sequence of events. The general scenario at each intersection was one in which a platoon of vehicles approached the intersection (from a direction that depended on the intersection and real accident), and the driver subject had to decide when it was appropriate to proceed through that intersection, in view of the positions and speeds of the opposing vehicles. In order to ensure that the vehicle platoon was at the proper location each time, the vehicle platoon matched the speed of the subject vehicle until the subject vehicle was very close to the intersection. Once it was close to the intersection, the vehicle platoon speed was set to the speeds encoded in the actual accident. To the driver subjects, the platoon spacing, position and speeds appeared to be effectively random.

Of the five different intersections, there were two general types: "left-turns" across oncoming traffic (3 intersections), and "crossings" of perpendicular traffic (2 intersections). The three left-turn intersections were MAIDS cases NL081, NL132, and IT074. The two crossing intersections were MAIDS cases NL035 and NL040. The platoon speeds were those actually recorded in each accident. The inter-vehicle gap sizes were selected so as to appear to be randomized overall, but also to present to the driver a so-called "medium risk" gap size in front of each opposing vehicle lighting treatment, to be described subsequently.

The general left-turn scenario is shown in Fig 2. As the subject vehicle approached the intersection, the vehicle platoon approached in the on-coming lane. The vehicle platoon included a lead vehicle, an opposing vehicle, and a trailing vehicle, with a distracter vehicle positioned on a cross street. When the lead vehicle passed the distracter vehicle, the distracter vehicle proceeded and turned left. The opposing vehicle was positioned at a fixed gap size behind the lead vehicle. If the opposing vehicle was a PTW, the gap size (bumper-to-bumper) was 3.7 seconds. If the opposing vehicle was a car, the gap size was 2.7, 3.7, or 4.7 seconds, randomized and equally distributed in frequency. The trailing vehicle was always 4.0 seconds behind the opposing vehicle. If the opposing vehicle was not present, the trailing vehicle was located 4.0 seconds behind where the opposing vehicle would have been, thus creating a gap of 7.7 seconds between the lead vehicle and the trailing vehicle.

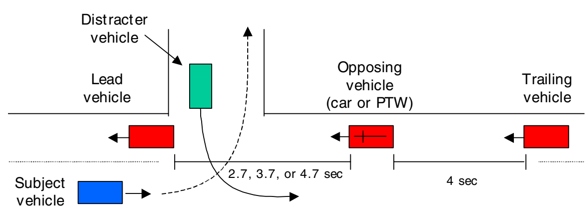

Figure 2. General left-turn scenario (NL081, NL132, IT074).

There were two different types of crossing intersections: a left-turn across perpendicular traffic (MAIDS case NL035), and crossing perpendicular traffic with a slight jog to the right (MAIDS case NL040). "Yield" signs were located at both intersections, so the subject vehicle usually came to a full stop before proceeding.

The first crossing intersection scenario type is shown in Fig 3 (left-turn across perpendicular traffic). As the subject vehicle approached the intersection, the vehicle platoon approached from the left. Again, the vehicle platoon included a lead vehicle, an opposing vehicle, and a trailing vehicle, with a separate distracter vehicle approaching from the right (the opposite direction). First, the distracter vehicle passed in front of the subject vehicle. Then the lead vehicle passed the subject vehicle shortly thereafter, as the subject vehicle was positioned at the "Yield" sign. The opposing vehicle was positioned at a fixed gap size behind the lead vehicle. If the opposing vehicle was a PTW, the gap size (bumper-to-bumper) was 3.0 seconds. If the opposing vehicle was a car, the gap size was 2.0, 3.0, or 4.0 seconds, randomized and equally distributed in frequency. The trailing vehicle was always 4.0 seconds behind the opposing vehicle. If the opposing vehicle was not present, the trailing vehicle was located 4.0 seconds behind where the opposing vehicle would have been, thus creating a gap of 7.0 seconds between the lead vehicle and the trailing vehicle.

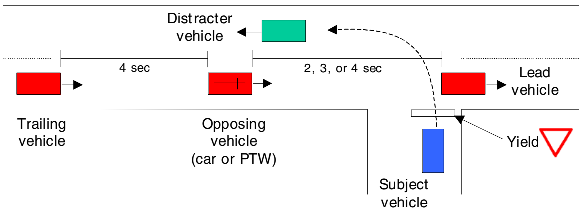

Figure 3. General crossing intersection scenario type 1 (NL035).

The second crossing intersection scenario type is shown in Fig 4 (crossing perpendicular traffic with a slight jog to the right). As the subject vehicle approached the intersection, the vehicle platoon approached from the right. The vehicle platoon included a lead vehicle, an opposing vehicle, and a trailing vehicle, with a separate distracter vehicle approaching from the left (the opposite direction). First, the distracter vehicle passed in front of the subject vehicle. Then the lead vehicle passed the subject vehicle shortly thereafter, as the subject vehicle was positioned at the "Yield" sign. The opposing vehicle was positioned at a fixed gap size behind the lead vehicle. If the opposing vehicle was a PTW, the gap size (bumper-to-bumper) was 3.0 seconds. If the opposing vehicle was a car, the gap size was either 2.0, 3.0, or 4.0 seconds, equally distributed. The trailing vehicle was always 4.0 seconds behind the opposing vehicle. If the opposing vehicle was not present, the trailing vehicle was located 4.0 seconds behind where the opposing vehicle would have been, thus creating a gap of 7.0 seconds between the lead vehicle and the trailing vehicle.

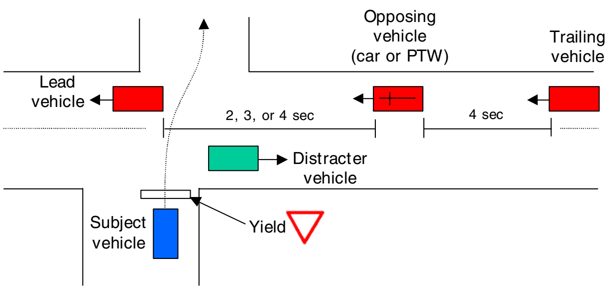

Figure 4. General crossing intersection scenario type 2 (NL040).

Subject Protocols

All driver subjects were given the same specific instructions at specific times. In general, subjects were instructed to drive "as quickly and safely as possible through the road course." Subjects were asked to follow road signs to a hospital while following speed limits for various portions of the road circuit: 50 km/h in "built-up" areas (the areas surrounding the intersections), and 80 km/h in all other places. The sound of a car horn was heard each time a speed limit was exceeded.

In order to provide a suitable and realistic driver workload, subjects were also asked to perform a radio tuning task at various intervals while driving. At various locations along the road circuit, a voice prompt told the subject to tune to a randomized radio station frequency. Tuning was accomplished by rotating a tuning knob located on the right side of the radio. The tunings were a simple, single-station tuning, with less than 10 MHz of movement between radio channels. Tunings were performed between most intersections, at seven different locations along the road circuit.

A structure of small monetary penalties and rewards was also implemented in order to encourage realistic driving behaviour. Subjects were told that they started each run with USD 4 and that each speed limit violation incurred a penalty of USD 1. In addition, a reward of USD 2 was given for road circuit completion within a certain time limit, and a penalty of USD 2 was incurred for exceeding the time limit. The actual time limit was arbitrary, although a typical circuit time would be about 8 minutes for realistic, "quick but safe" driving.

Drivers were encouraged, by means of controlled comments from the Experimenter, to adopt a moderate rate of choosing to "GO" in front of the opposing vehicle, since no useful information would be gained from drivers always going or never going in front of the opposing vehicles. This was found to be necessary because it was observed during the Pilot Tests that, over long periods of time, drivers behaviour tended to "drift" gradually toward either an "always GO" pattern (representing a very high level of risk, or so-called "video game" behaviour); or toward a "never GO" pattern (or "zero risk") behaviour. Whilst such behaviors may or may not occur in the real world, the objective of the research was to examine the so-called "medium risk" situations most typical of real accidents, namely, those situations in which there is roughly an equal probability of "GO" or "no GO." These are situations that require conscious sensing, recognition, speed-distance estimation and decision-making by drivers, which was the main objective of these experiments.

In view of these objectives and factors, the following protocol was implemented in the last Pilot Test and in the Main Tests. If and when drivers did not choose at least 1 "GO" in the most recent 5 intersections, they were read the following statement:

> "In order to receive your time bonus, you may need to take more risk at the intersections."

If and when drivers chose at least 4 "GOs" in the most recent 5 intersections, they were read the following statement:

> "You can still receive your time bonus even if you do not take quite so much risk at the intersections."

In this way, the subjects were allowed (but not forced) to adjust their risk level. This was done in such a way, in the presence of randomized gap size and treatment, that the subjects tended to choose a "medium risk" level, overall. No other coaching or discussion in relation to this was given.

Example Treatments

Overall, a total of 15 lighting treatments were used in various phases of the study. Pilot Test 1 examined the greatest number of treatments, while Pilot Tests 2 and 3 were used to refine the final selections for the Main Tests.

Figure 4 illustrates the approximate appearance of the baseline lighting treatment selected for use in the Main tests. This comprises a "sport" type moped with a sport type motorcycle headlamp of 186 mm diameter and 273 cd at the opposing driver's eye point (DEP) location.

Ultimately, hypothetical treatments were selected for use in the Main Tests based in part on:

- Total intensity (detection theory)
- Multi-lamp separation (speed-distance estimation theory)
- Signature/pattern and signature/colour (recognition theory)

These criteria and the results of pilot testing were used to select the final treatments for the Main Tests.

Figure 4. Appearance of baseline lighting treatment.

Photometric Calibration

Photometric calibrations of the lighting treatments were conducted in order:

- To compare simulated and real-world daytime contrast ratios for treatments;
- To determine the feasible contrast ratio for the Driving Simulator;
- To establish a maximum simulated luminance value for the simulator tests.

The first step was to examine luminance measurements that would occur at a typical Driver Eye Point (DEP) for the various lighting treatments that would be used in the testing. Next, laboratory measurements of an existing headlamp were made. Then real-world daytime luminance and contrast ratio measurements were taken. Then the maximum luminance to be simulated was established from the various lighting measurements that had been made. Finally, luminance measurements were made in the Driving Simulator of the implemented lighting treatments, and contrast ratios were calculated and compared to those from real-world conditions.

Generally speaking, for this series of daytime lighting experiments, it was found that a simulated maximum contrast ratio (i.e., saturated white-to-18% horizontal grey card surface) of 6.4 to 1 was sufficient to capture the real-world contrast ratios present with current typical car and PTW normal headlamps under typical "bright" daylight conditions.

The ambient lighting of the scene was therefore adjusted to achieve this contrast ratio with the brightest of the treatments set to saturated (pure) white. The contrast ratio as used here is defined as the ratio of the luminance of the lighting treatment as measured at the DEP minus the luminance of the background as measured at the DEP, divided by the luminance of the background. The standard luminance of the background was taken to be 1750 cd/m^2 based on mid-day luminance measurements using a horizontal 18% grey photographic reference card, recorded outdoors at 35 degrees north latitude during several weeks around the vernal equinox, under a wide variety of cloud conditions. This was considered to represent typical worst-case "bright" conditions. Darker daytime ambient lighting (as in more northern latitude and/or winter conditions) would be expected to lead to higher detection and effectiveness of the lighting treatments studied, and in addition are less representative of typical motorcycle operating conditions.

The screen luminance of all of the simulated scenes as measured at the DEP were in the photopic (i.e., greater than 1 cd/m^2) region, and therefore, although they were 1000 times (i.e., 60 decibels) dimmer than full-scale, they involved the same human sensory apparatus (i.e., photopic luminance contrast) as full-scale.

In all other regards, the simulated luminance of each headlamp was modeled in the Simulator in accordance with the lighting manufacturer data, as a function of the vertical and horizontal angles from the driver's eye to the headlamp central axis, and the distance-squared from the headlamp to the driver's eye.

Experimental Matrix

The Main Tests involved 10 driver subjects and examined 4 different PTW lighting treatments. The overall experimental variables included the 4 PTW lighting treatments, 5 unique intersections, 2 DRL mixes, and 2 repeats. A single gap size was used when the PTW was the opposing vehicle. The experimental variables and the total runs required are shown in Table 5. The experimental variables resulted in a total of 24 road circuit loops per subject.

Table 5.
Main test experimental variables and total runs required

Number of intersections	5
PTW Lighting treatments (baseline and 3 others)	x 4
Gap size (PTW as Opposing vehicle)	x 1
Percentage of Cars having lights on (10 or 90%)	x 2
Repeats	x 2
PTW exposures per subject:	= 80
(33% occurrence rate of PTWs)	x 3
Intersections required per subject:	= 240
Intersections per road circuit loop:	/ 10
Total number of road circuit loops per subject:	= 24

Measurements

For each run (i.e., one lap of the circuit), several different types of data were collected. Continuous time history data were collected, including:

- Positions of all vehicles
- Speed
- Brake pedal force
- Throttle pedal position
- Lateral and longitudinal acceleration
- Steering wheel angle

Driver eye fixations on the opposing vehicle were also collected from a head-mounted eye tracker. The time of the driver's first fixation on each opposing vehicle was recorded in post-processing of the video data, and the resulting variable was the distance to the opposing vehicle at the time of the first fixation.

Two video recordings were made. One recording was of the split images of the driver's face, forward road scene, and cab interior, shown in Fig 6. Note that the driver is wearing the eye tracking equipment; the area around the eye that appears to be lit is infrared wavelength light and therefore not visible to the driver. The second video recording was from the head-mounted wide angle camera, with the eye fixation crosshair superimposed, shown in Fig 7.

(1)  (2)

(3)

Figure 6. Split images of driver face (1), forward road scene (2), and cab interior (3).

Figure 7. Video image from head-mounted camera, at an instant when eye is fixated on PTW, and head is facing left window of car.

METHODOLOGY VALIDATION

In addition to the pilot testing, validation tests were performed in order to compare driver detection of vehicles in real world (full-scale) versus the simulator. The technical approach was to measure and compare motorcycle detection rates using full-scale and simulator occlusion experiments.

The protocols and setup for full-scale testing and simulator testing were the same. Both phases of the validation test used the same subject. The methodology was somewhat similar to that used by Donne et al. (1985) comprising a forward view occlusion test with a scene geometry somewhat similar to that of Cobb (1992).

The subject was seated in the driver's seat of a parked vehicle, wearing occlusion goggles that gave a 0.100 sec glimpse of the forward scene. This glimpse time was similar to that used by Donne et al. (1985), and consistent with human glance durations, which can be about 0.070 sec and greater. A motorcycle, car, both or neither would be presented to the subject. The motorcycle, if present, appeared in front of the subject in 1 of 4 possible locations, and the car appeared in 1 of 3 possible locations. The motorcycle headlamp could be on or off, and the car headlamp was always on. After the occlusion shutter was opened then closed, the subject was asked:

- Which vehicles were seen?
- Where was each vehicle located? and
- Was each vehicle's headlamp on or off?

Upon completion of full-scale and simulator testing, the data was reduced and analyzed. Vehicle detection was the primary concern, with headlamp detection being of secondary interest. The possible vehicle detection error types were: omission errors, insertion errors, and substitution errors. Omission errors occurred when a vehicle was present, but not reported. Insertion errors occurred when a vehicle was not present, but was reported. Substitution errors occurred when a vehicle was present, but was reported as another vehicle type (car or motorcycle). Of the different error types, omission errors were considered to be the most important with respect to motorcycle conspicuity.

Overall, omission error rates were similar in full-scale and simulator testing. All motorcycle omission errors occurred with the headlamp off. More omission errors occurred to the left, which was a somewhat larger visual angle from the subject's line-of-sight than the position to the right. No errors of omission occurred in the centre positions.

The probability of motorcycle detection that resulted from the full-scale and simulator testing was also compared to a simple hypothesized, detection probability model using a primitive "detection index" (DI). This index was similar to the "area-weighted contrast" models mentioned by Blackwell (1946) and Witus et al. (2001) as historical models for describing human detection of simple objects against plain backgrounds. The index is defined in Equation 1 as:

$$DI = | \text{Area x Contrast ratio} | \qquad (1).$$

Such primitive models have been found to be of less value in complex scenes involving complicated targets and cluttered backgrounds. This equation is valid for one exposure time (in this case, 0.100 sec) in time-dependent models such as those discussed by Witus et al. (2001).

The hypothesized "probability of detection" model, shown in Equation 2, is a simple heuristic model of logistic form, as a function of the hypothesized detection index, and with a correction for eccentricity (i.e., horizontal angle from the line of sight).

$$\text{Probability of detection} = (1 - e^{-DI/b}) \cos^{b/DI} \Phi \quad (2).$$

where: b = detection constant
Φ = horizontal angle

The exponential cosine correction is suggested as being similar in form to the data presented by Arnow and Geisler (1996).

Figure 8 shows the probability of motorcycle detection for the hypothesized detection index model (fitted to the current data), as well as for the full-scale and simulator tests. The full-scale and simulator tests include data for both headlamp-on and headlamp-off. For all cases, at a 5 degree offset (foveal view) the probability of detection was the same, at 1.0. At a 35-45 degree offset (peripheral view) the probability of detection was slightly greater in the Simulator than in full-scale. Figures 9 and 10 show the probability of detection for headlamp-on and headlamp-off conditions. In the headlamp-on condition, the probability of detection was 1.0 for all angles in both full-scale and simulator tests. For the headlamp-off condition, the probability of detection in full-scale for the right peripheral view was about 0.9 and for the left peripheral view was about 0.8, being somewhat greater than this in the Simulator.

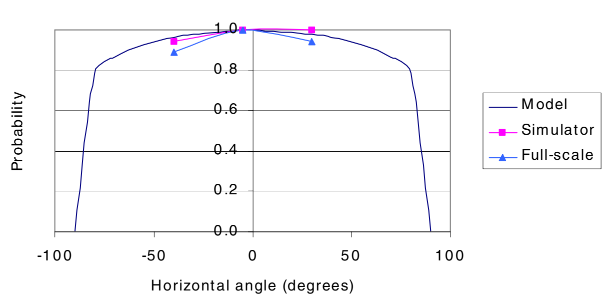

Figure 8. Probability of motorcycle detection for model, simulator, and full-scale tests, all conditions.

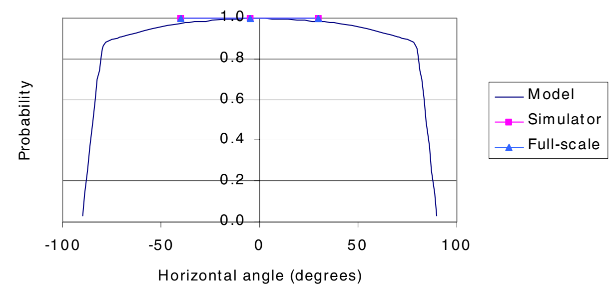

Figure 9. Probability of motorcycle detection for model, simulator, and full-scale tests, headlamp-on conditions.

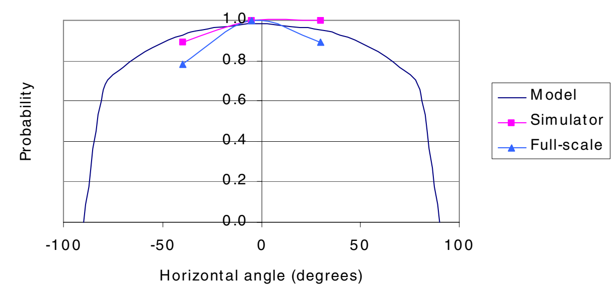

Figure 10. Probability of motorcycle detection for model, simulator, and full-scale tests, headlamp-off conditions.

Validation Test Conclusions

The results of Validation Testing indicate that for short 0.100 second glances at 5 degrees, the simulator gave the same probability of detection as full-scale for all motorcycle headlamp on/off conditions. At 35-45 degrees, the simulator gave the same probability of detection as full-scale for headlamp-on conditions. At 35-45 degrees, the simulator gave somewhat greater probability of detection than full-scale for headlamp-off conditions. One possible reason for this difference might be that "solar glare" from the car in the full-scale test competed with the headlamp-off motorcycle.

In general, solar glare reflections from vehicles and the environment in sunny conditions can be much brighter than, and can reduce the effectiveness of, typical dipped beam headlamps (not to mention the conspicuity of a headlamp-off vehicle). In full-scale outdoor tests, the amount of solar glare can vary over time, and is an extraneous variable. A driving simulator can control and keep the solar glare constant. So in order to minimize the effects of extraneous variables, it was concluded that the simulator tests should use "cloudy-overcastbright" conditions and not excessive levels of object shininess or "specularity." These conditions are typical for much of Europe in much of the motorcycle riding season.

Overall, the results of the Validation Tests also suggest that the effectiveness of lighting treatments measured in the simulator might be less in the real world for large horizontal viewing angles (e.g., crossing-type accidents) in sunny regions. In fact, the Main Test lighting treatments (which were dipped beam headlamps) were not so effective in such "wide angle" conditions, even in the Simulator. Otherwise, the simulator was found to give accurate and valid results for the rapid glimpse conditions examined, in comparison to real world full-scale motorcycle detection rates.

Finally, a simple rough "Detection Index" model was able to describe, at least in form, the main "probability of detection" effects observed in the Validation Tests.

EXAMPLE DATA FROM MAIN TESTS

Whilst presentation and discussion of the detailed results of the Main Tests is beyond the scope of the current paper, the purpose of which is to describe the experimental methodology, nevertheless, a few examples of typical resulting data illustrate the discriminating power of the methodology.

Several hypothetical frontal lighting treatments were considered, with four (A, B, C and D) being evaluated in the Main Tests. Treatment A was the baseline PTW treatment previously described. None of the hypothetical treatments B, C or D considered real-world practicability. Data for cars is also shown.

Statistical differences between sets of data were reported when appropriate. The statistical test that was typically performed was an independent samples t-Test. The output of the statistical test is a p-value, where values less than 0.05 indicate a significant difference between the data sets.

The probability of eye fixation on the opposing vehicle was analyzed by PTW treatment, shown in Fig 11. The overall probability of eye fixation was lower for PTWs than for cars, but the difference in fixation probability was not significant (p=0.17). None of the PTW lighting treatments were significantly different from the others in terms of the probability of eye fixation. However, the probability of eye fixation on a car was significantly greater than for PTW treatments C (p=0.04) and D (p=0.03), while differences from PTW treatments A (p=0.06) and B (p=0.08) were not significant.

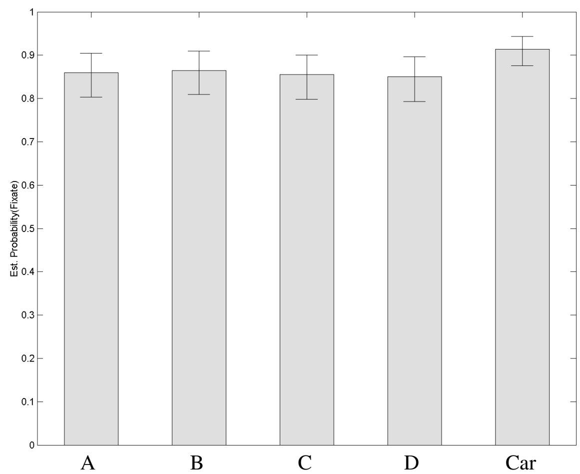

Figure 11. Probability of eye fixation on opposing vehicle for treatments.

Figure 12 shows the distance to the opposing vehicle at the 1st eye fixation for both left-turn and crossing intersections. This was the distance where the driver subject first observed the opposing vehicle. For left-turn intersections, the fixation distances were similar. For crossing intersections, the mean fixation distance for Treatment A was 5 to 8 m less than for the other (greater intensity) PTW treatments and for cars, but this difference was not significant.

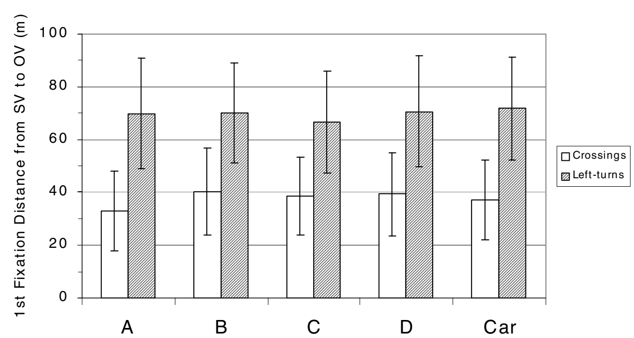

Figure 12. Distance to opposing vehicle at 1st eye fixation, left-turn and crossing intersections.

The probability of "GO" was analyzed by PTW treatment and combined across intersection type, shown in Fig 13. Overall, cars had a significantly lower probability of "GO" than PTW treatment A. Also, PTW treatment B and cars had significantly lower probability of "GO" than PTW treatment D.

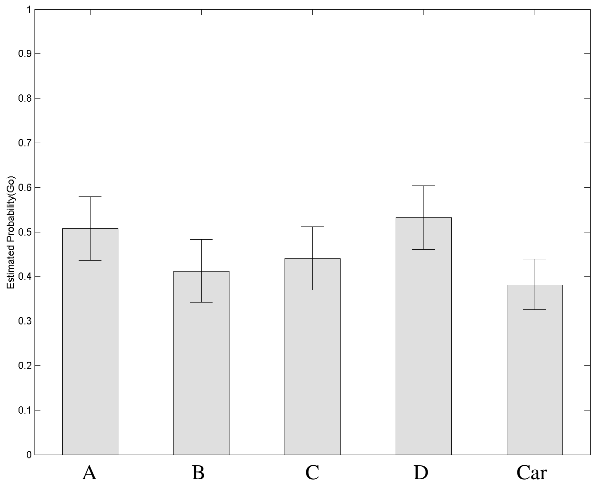

Figure 13. Probability of "GO" by treatment.

The cumulative distributions of minimum distances to the opposing vehicle in "GO" conditions were combined across intersection type, and graphed on a normal probability scale shown in Fig 14. The linear distributions when graphed on a "normal" scale indicated that the distributions were "normal." This increased the reliability of the intercept (i.e., collision probability) calculation. Overall, PTW treatment A had the greatest probability of collision overall, having the greatest number of near-miss incidents. PTW treatment B had the least probability of collision overall.

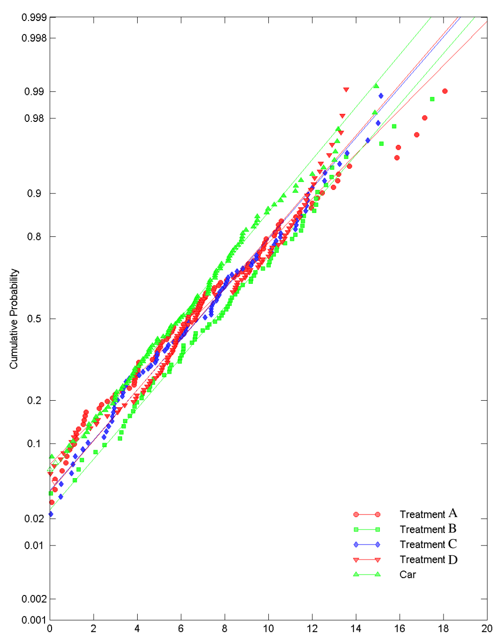

Figure 14. Cumulative distributions of minimum distances to opposing vehicles.

Probability of Collision

The overall probability of a collision was defined as the probability of a "GO" multiplied by the probability of a collision given a "GO," shown in Equation 3:

$$P(\text{Collision}) = P(\text{"GO"}) \times P(\text{Collision})|_{\text{"GO"}} \quad (3).$$

The data for these calculations, given in the previous subsection, was pooled over all 10 driver subjects. The probability (or estimated observed frequency) at 0 distance indicates the probability of a collision, and a constant slope when graphed on a "normal" scale indicates a normal distribution.

Figure 14 (shown previously) is the cumulative distribution of minimum distances to the opposing vehicle and Fig 15 summarizes the resulting probability of collision for each PTW treatment. Treatment B had by far the lowest mean probability of collision, and this was significantly lower than Treatment A.

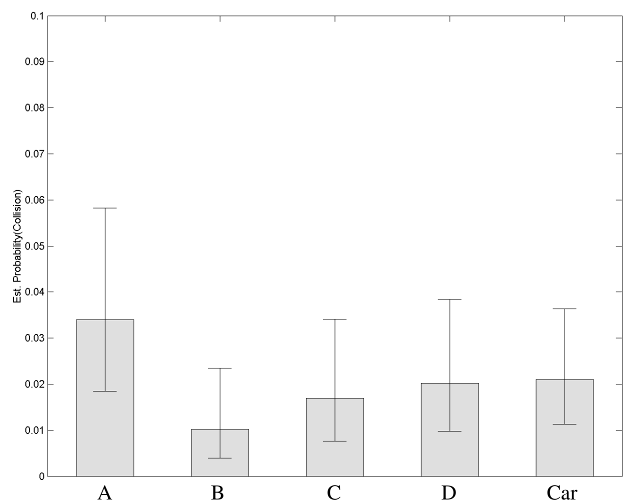

Figure 15. Probability of collision for each PTW treatment.

Preliminary Overall Effectiveness Estimate

The preliminary estimated overall effectiveness of each PTW lighting treatment was calculated using the Main Test data and aggregated MAIDS data for the various categories of accidents.

The methodology used to make these estimates used both quantitative data from the simulator experiments and from the MAIDS accident database, and subjective judgments of "effectiveness weighting" in each category of MAIDS accident.

The method first listed 129 relevant categories of PTW accidents using the OECD Common Methodology Data Summary Sheets. Next, the number of cases in MAIDS falling into each accident category was listed. Next, it was noted that in 37% (337) of the n = 921 MAIDS accidents, "other vehicle driver perception failure" was coded as the primary contributing factor (and this was the largest primary contributing factor). It was assumed that the visual background had a negative effect on motorcycle conspicuity in some of these cases of "other vehicle driver perception failure." Therefore, the MAIDS data was evaluated in order to develop an estimate of the number of PTW accident typologies that may have included a visual background that had a negative effect upon PTW conspicuity.

The data from MAIDS indicated that the visual background had a negative effect on MC conspicuity in n = 112 cases. This is 33% of the n = 337 "OV driver perception failure" cases.

CONCLUSIONS

An experimental investigation was conducted to verify whether potential PTW conspicuity improvements could be studied in driving simulator experiments. The driving simulator consisted of an instrumented car with interactive steering, braking and throttle controls; a 180-degree high resolution real-time visual display; a road circuit involving five real accident sites and scenarios from the Motorcycle Accidents In Depth Study (MAIDS); left turn and crossing intersections with randomized gap size in front of opposing vehicles; 3D photographic images of the accident sites; and motorcycle and car lighting treatments photometrically calibrated against full-scale in terms of measured luminance contrast ratios.

In addition to photometric calibration against real headlamp contrast ratio data, the simulator was validated using human visual occlusion tests involving vehicle detection. In these tests with 0.100 sec glimpse times, the driver's detection of motorcycles in the simulator was identical to that in the full-scale tests under most conditions (i.e., in the foveal, or central, zone), with headlamp-on and headlamp-off; and in the peripheral zone with headlamp-on); and only somewhat greater than in the full-scale tests in one condition (peripheral, headlamp-off). The latter small difference is attributed to the presence of solar glare in the full-scale tests. This extraneous and variable condition reduced the conspicuity of the motorcycle headlamp-off condition. Overall, the validation tests indicated that the simulator is valid for rapid detection tasks in the foveal as well as the peripheral regions.

Main Tests were conducted with n = 10 European car drivers, and involved full-task, "blind" experiments in the calibrated and validated driving simulator. Driver subjects did not know the true purpose of the experiment, which involved realistic driving in urban and rural conditions and various primary and secondary realistic driving tasks. A protocol was developed which resulted in all subjects driving with similar levels of "medium risk" at intersections.

Measurements were made of driver eye fixations (i.e., detection) of opposing vehicles (i.e., PTWs or cars); probability of "GO" in front of an opposing vehicle; and minimum distance to the opposing vehicle, enabling calculation of the "probability of collision." Each driver subject (10) was exposed to each lighting treatment (4) at each accident site (5) twice for two different car DRL conditions, yielding a total of n = 800 treatment exposures.

Overall, the simulator methodology was found to provide a powerful tool for researching differences in driver behaviour and collision probability due to daytime lighting treatments in this sample of real accident scenarios.

RECOMMENDATIONS

An initial peer review with experts from the human factors and lighting research communities has suggested that whilst the simulator methodology appears to be robust and valid, further validation and application would be helpful, in terms of elucidating and extending the initial findings. This additional research could include: investigating various simulator and protocol issues (e.g., driver short term learning effects; separating the effects of driver long term learning and background DRL percentage changes; wider variations in speed and intersection type); further validation of detection with greater numbers of drivers; validation in over-the-road experiments; investigation of a wider range of treatments and technologies; and refinement of the overall effectiveness estimation method.

The simulator methodology might also be useful in the in-depth and realistic evaluation of other safety technologies, such as telematics and e-safety, which aim at improving PTW conspicuity.

ACKNOWLEDGEMENTS

This work was funded by the Association des Constructeurs Européens de Motocycles. Thanks are expressed to Philips Automotive Lighting Group for providing valuable lighting data and information. Acknowledgment is also expressed to Amanda Kwok, Paul Satrom, and Kevin Chao for their valuable contributions to the DRI simulator experiments.

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SIMULATION OF MOTORCYCLE-CAR COLLISION

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ABSTRACT

Numerical simulation of motorcycle-car collisions is one of the most effective tools in research on motorcycle passive safety, considering the diversity of collision configurations. In addition, due to the length of analysis time to be considered, the multi-body dynamics-based software "MADYMO" (MAthematical DYnamic MOdel) rather than FEM based software has been adopted as a basic simulation tool.

In this research, a scooter-type motorcycle model for collision simulation was developed. Detailed modeling steps of the motorcycle model were presented in 18th ESV [1]. This paper presents 1) a general description of a motorcycle, car and dummy model for collision simulation, and 2) comparisons between the FST (Full Scale Test) and a simulation in which these models are used. As for collision configurations of FST, several of seven basic impact configurations recommended in ISO13232 [2], which defines test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles, were selected. The corresponding simulations were then carried out. As a result of validating the model with FST data, the dummy kinematics and dummy signals (such as head acceleration) obtained in simulations show qualitatively good agreement with FST results.

INTRODUCTION

The aim of this simulation is to develop a tool to evaluate rider protective devices and therefore to reduce rider injuries when a motorcycle-car accident occurs. One feature of motorcycle-car accidents is their diversity of collision configurations. In ISO13232, 200 configurations are recommended to evaluate rider protective devices. Another feature of motorcycle-car collisions is that the rider is likely to experience secondary impact with the environment (such as the road) and therefore the analysis time to be considered is much longer than that in car-to-car collisions. Considering these specific features, multi-body dynamics-based software MADYMO was adopted as a basic simulation tool.

In this simulation, a scooter-type motorcycle model (a prototype test vehicle), a rider dummy model and a car model are used (see Figure 1). A part of this paper gives a general description of the motorcycle, the dummy and the car model. Using these models, several simulations of seven basic configurations recommended in ISO13232 were carried out. On the other hand, corresponding FSTs (Full Scale Tests) were also performed. In addition to the basic steps of modeling such as component tests and barrier tests, these FST data greatly contributed to refinement of the simulation model. As a result of the validation process, comparisons between simulations and FST results are also shown herein.

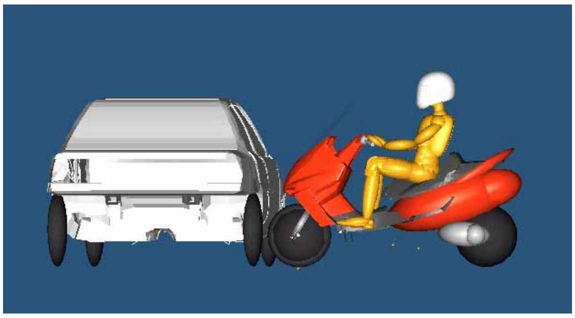

Figure 1. Full simulation model.

MOTORCYCLE MODEL

Our motorcycle model (see Figure 2), which is a rigid model, consists of 21 rigid bodies, 12 movable joints and many surfaces. In MADYMO [3], an ellipsoid, cylinder, plane and facet surface are used for the surface. The surface is attached to the rigid body to visualize the model or to calculate the contact force. A facet surface, which is an FEM mesh-like surface but not deformable, is used when more precise contact force is required.

Figure 2. Motorcycle model.

Detailed modeling steps of the motorcycle model were provided in the previous paper [1]. From that time on, several additional component tests were performed to determine the contact characteristics of the motorcycle in case of rear and side impact. Some small ellipsoids were replaced by the corresponding facet surfaces to avoid an irrational contact force caused by a certain algorithm to generate a contact force.

RIDER DUMMY MODEL

The Hybrid Ⅲ standing model (see Figure 3) in MADYMO database is used as a rider dummy model because it had been employed in the FST. This dummy model is a rigid model with 32 rigid bodies and 51 ellipsoids originally, but now some ellipsoids have been replaced by the facet surfaces for the same reason as in the case of the motorcycle model. In addition, the bending characteristics of the neck were adjusted by doing pendulum test simulations.

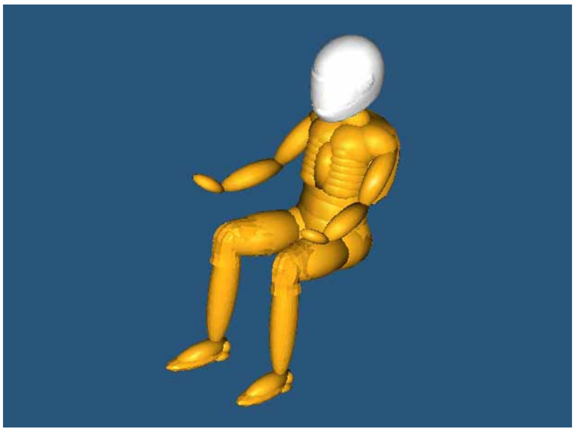

Figure 3. Rider dummy model.

A helmet model, which is also a rigid model and has a fine facet surface, was attached to the dummy model. The contact characteristics of the helmet model were determined using various conditions for the component test.

CAR MODEL

An existing FE (Finite Element) model was appropriated for a car model. This car model (see Figure 4) originally had approximately 47,000 nodes and 40,000 elements. After re-meshing for the purpose of reducing calculation time, it has approximately 27,000 nodes and 19,000 elements. The four tires are replaced by ellipsoids for the same reason.

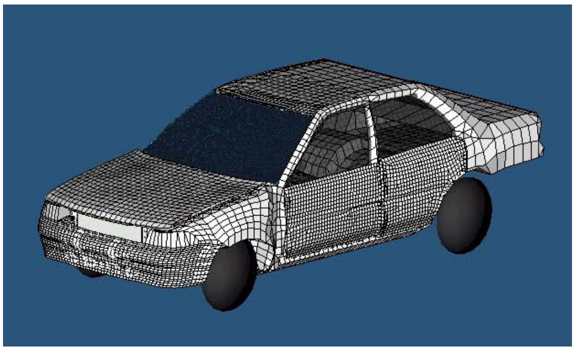

Figure 4. Car model.

ISO13232 SEVEN BASIC CONFIGURATIONS

As mentioned before, ISO13232 specifies seven basic impact configurations (Figure 5). The impact configuration code (such as “413-0/13.4” in Figure 5) comprises a series of three digits describing the car contact point, the motorcycle contact point and relative heading angle, respectively, followed by a hyphen (-), the car impact speed, and the motorcycle impact speed, respectively in m/s. Researchers are recommended to carry out these configurations of FST and validate their simulation model using these test data. We have already finished several FSTs and validated corresponding configurations of the simulation model. Hereafter these results are shown.

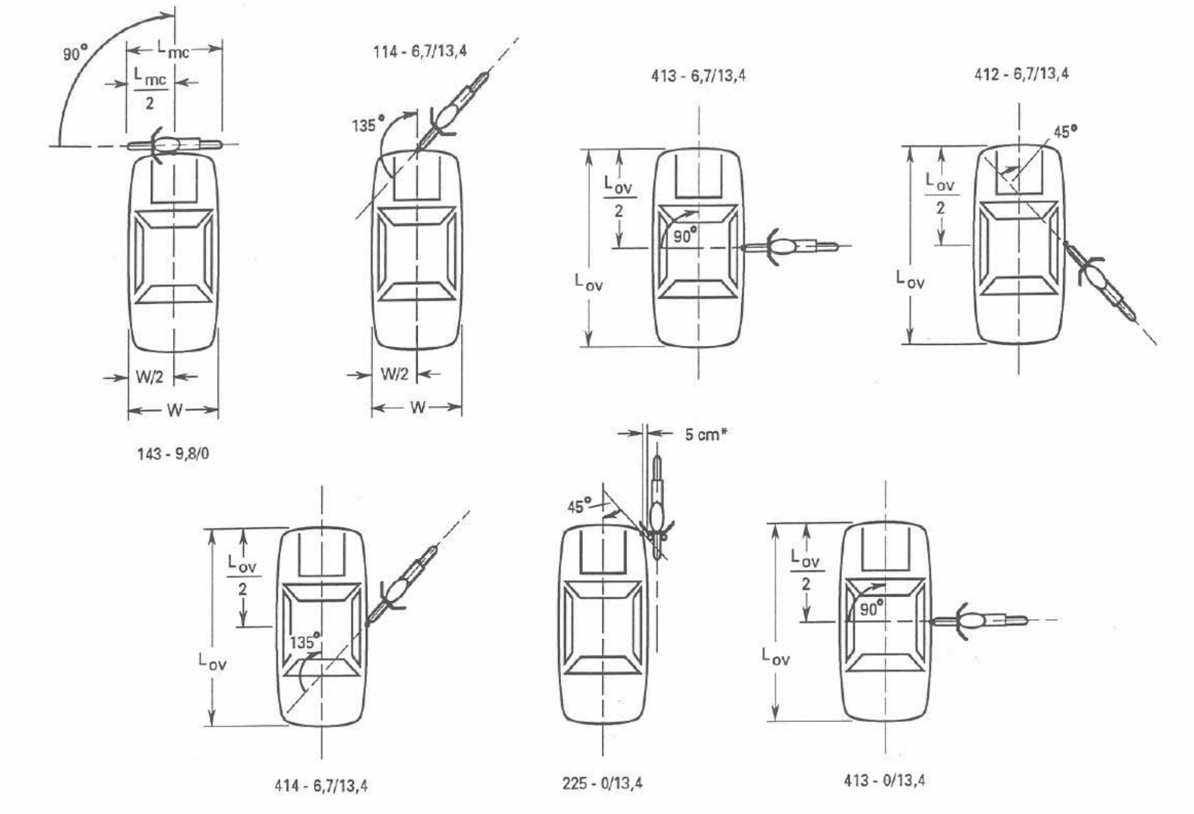

Figure 5. ISO13232 seven basic configurations.

FULL MODEL SIMULATION

Combining the motorcycle, the rider dummy and the car model, a full model simulation corresponding to each FST was carried out. At first, four basic configurations, in which the motorcycle collides with the side of the car, were selected. In each case, a validation process such as adjusting a contact force or a friction coefficient was performed. As a result of these detailed and cumulative efforts, our model proved to show good agreement in dummy's kinematics and head resultant acceleration data. In ISO13232, the maximum allowed tolerances between FST and simulation for the dummy's displacement and velocity about its head (helmet) and hip point, are specified. In addition, the correlation coefficient about the head maximum resultant linear acceleration should be calculated. Figures 6 to 9 show kinematic comparisons between FST and simulation from 0 ms (at which time the first motorcycle/car contact occurs) to 500 ms at time intervals of 100 ms. Table 1 lists what each figure shows. For example, Figure 6 shows a kinematic comparison in case of configuration code "413-0/13.4".

Table 1.
List of Figures.

Configuration code	Kinematic comparison	Head acceleration comparison	Configuration diagram
413-0/13.4	Figure 6	Figure 10	not moving 13.4 m/s
413-6.7/13.4	Figure 7	Figure 11	6.7 m/s 13.4 m/s
414-6.7/13.4	Figure 8	Figure 12	6.7 m/s 13.4 m/s
412-6.7/13.4	Figure 9	Figure 13	6.7 m/s 13.4 m/s

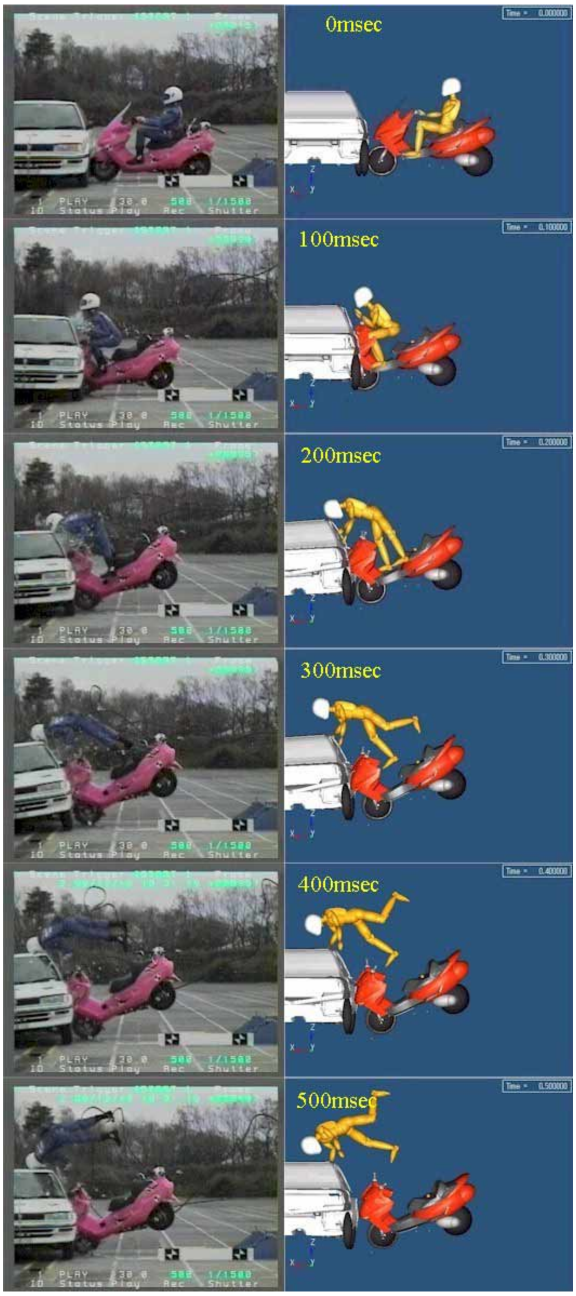

Figure 6. Kinematic comparison (413-0/13. 4).

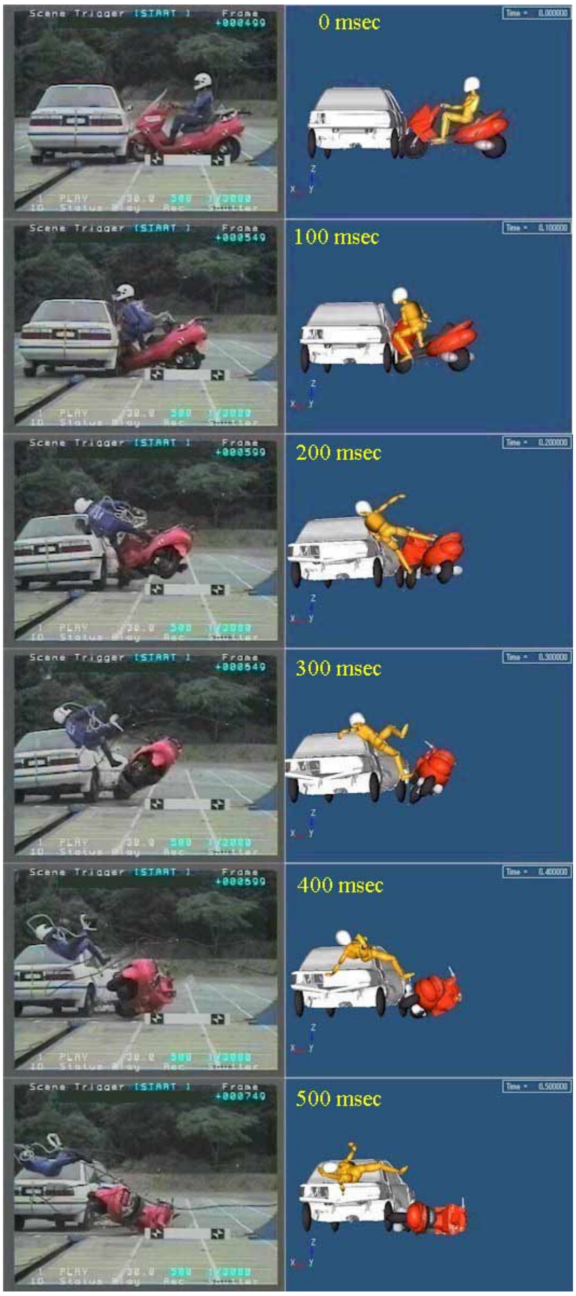

Figure 7. Kinematic comparison (413-6.7/13.4).

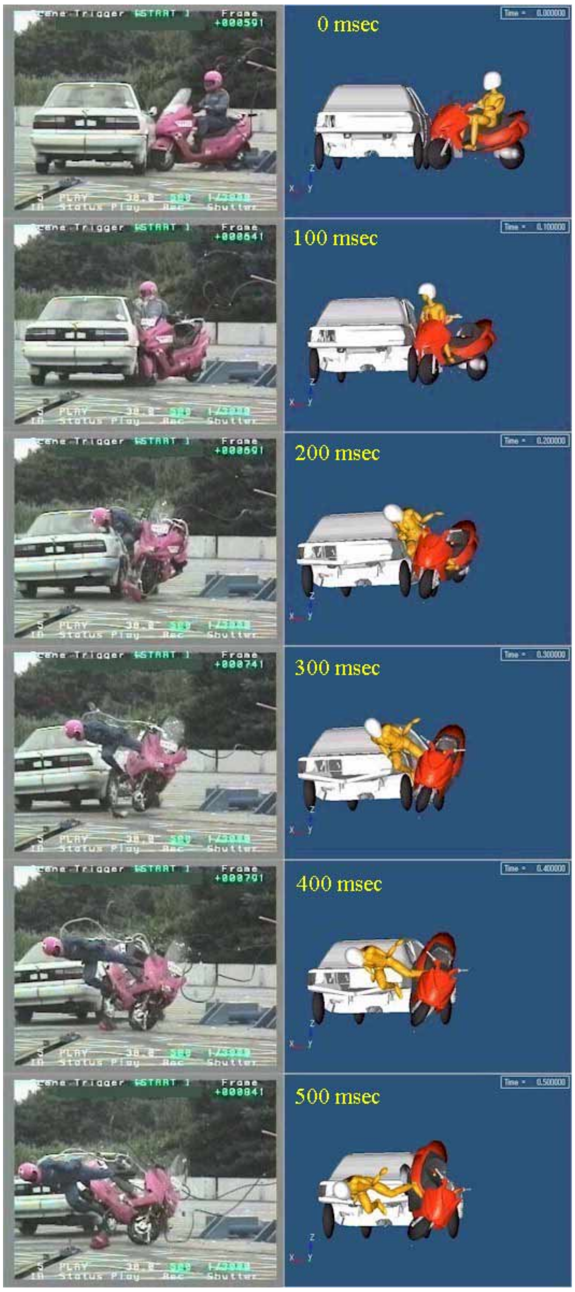

Figure 8. Kinematic comparison (414-6.7/13.4).

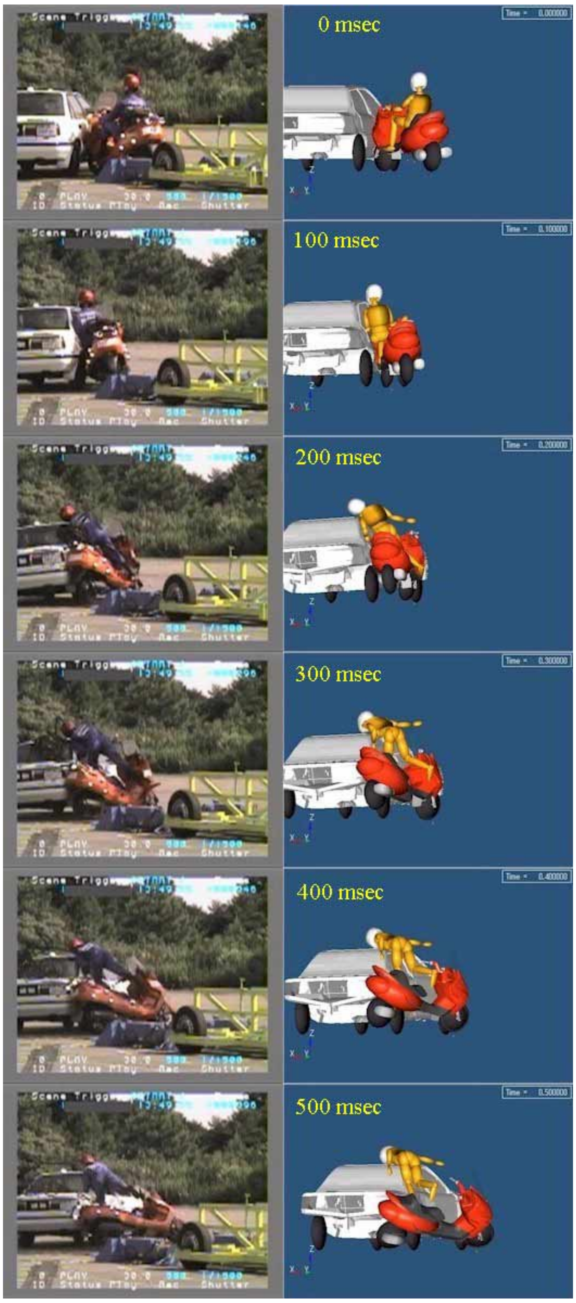

Figure 9. Kinematic comparison (412-6.7/13.4).

These figures show good kinematic agreement especially in the dummy's head and hip point position.

As listed in Table 1, Figures 10 to 13 compare the head resultant acceleration between FST and simulation. The blue lines indicate test data and light blue lines simulation results. And the same scale is adopted for all vertical axes.

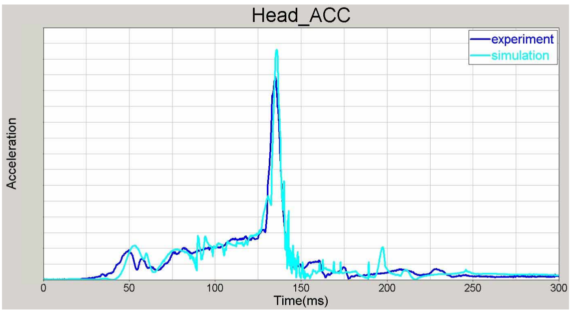

Figure 10. Head resultant ACC (413-0/13.4).

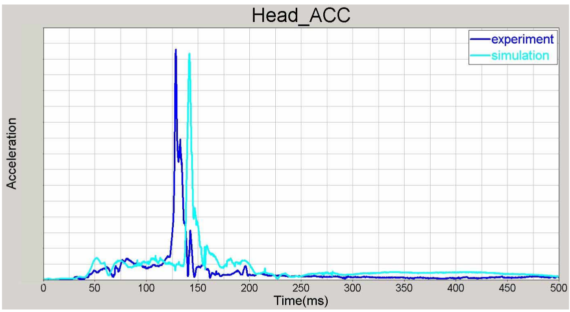

Figure 11. Head resultant ACC (413-6.7/13.4).

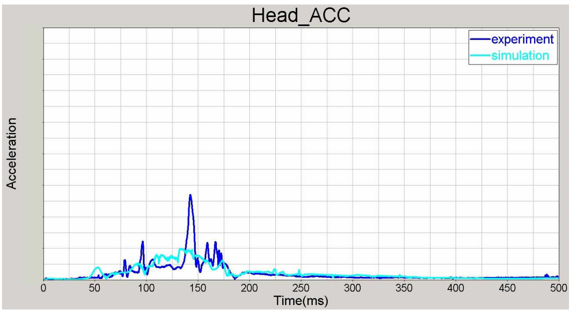

Figure 12. Head resultant ACC (414-6.7/13.4).

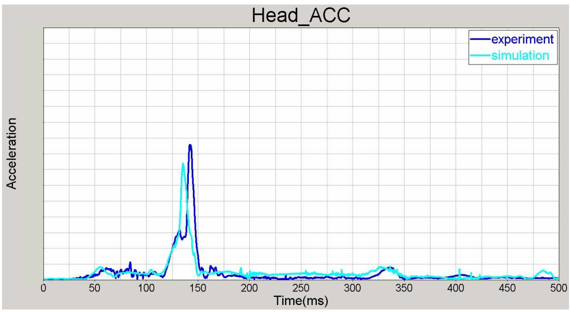

Figure 13. Head resultant ACC (412-6.7/13.4).

In these figures, fairly good agreement with the dummy's head resultant acceleration is observed. In case of 413-6.7/13.4 (Figure 11), the peak timing in simulation is slightly later than that in FST. And in case of 414-6.7/13.4 (Figure 12), the peak value of simulation is far below that of FST, though its absolute value is very small compared to other cases. In this case, the helmet of the rider dummy had a slight contact with a pillar of the car in FST, but no contact in simulation. The reason for the first difference is considered mainly that the contact between the motorcycle front cowl and the dummy's knee is not fully reproduced. In the second case, the contact between the car and the motorcycle front tire is considered to be the reason for the difference. Although there may be a more elaborate model, thus far, our model is considered to have sufficient accuracy to predict the dummy kinematics for practical use.

CONCLUSIONS

A scooter-type motorcycle model, as well as a rider dummy model, had been developed and some modifications were introduced. Using the motorcycle model, the dummy model and a car model, Full model motorcycle/car collision simulations were carried out. In several of the ISO13232 seven basic configurations, satisfying agreement in dummy kinematics and the dummy head acceleration was obtained. This means that an effective tool for evaluating rider protective devices is being developed. We will continue to validate three other cases and improve the model, and to utilize this simulation method to effectively evaluate and develop rider protective devices.

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MOTORCYCLE IMPACTS INTO ROADSIDE BARRIERS – REAL-WORLD ACCIDENT STUDIES, CRASH TESTS AND SIMULATIONS CARRIED OUT IN GERMANY AND AUSTRALIA

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ABSTRACT

Roadside protection systems such as steel guard rails or concrete barriers were originally developed to protect occupants of cars and/or trucks – but not to protect impacting motorcycle riders. Motorcycle rider crashes into such barriers have been identified as resulting in sever injuries and hence has become a subject of road safety research. The German Federal Highway Research Institute (BASt) requested DEKRA Accident Research to analyse real-world crashes involving motorcycles impacting road side barriers and to identify typical crash characteristics for full-scale crash tests of a conventional steel system and a concrete barrier. A study of 57 real-world crashes identified two crash test scenarios which have been carried out: one with the motorcycle driven in an upright position and one with the motorcycle with the rider sliding on the road surface. The pre-crash velocity chosen was 60 km/h. The impact angle was 12° for the upright driven motorcycle and 25° for the motorcycle and rider sliding.

Two crash tests have been conducted to analyse impacts onto conventional steel guard rails and two tests to analyse impacts onto a concrete barrier. Two additional full-scale crash tests were carried out to analyse the behaviour of a modified roadside protection system made from steel.

A second phase of the work involved carrying out computer simulations at Monash University's Department of Civil Engineering. The DEKRA results from the crash test, where the upright motorcycle impacts the concrete barrier, were used to validate a MADYMO motorcycle-barrier model. This model was then used to investigate other impact speeds, a 25° impact angle scenario and different impact scenarios between an upright motorcycle and a wire rope barrier system. The results revealed~~,~~ that the risk for motorcyclists of being injured when colliding with either a wire rope or a concrete barrier will be high.

The paper describes the relevant real-world accident scenarios, the different roadside protection systems used for the tests, the crash tests, the modelling simulations and the results, and proposes improvements to barrier systems to reduce injury severity.

INTRODUCTION

In Germany, the most common roadside protection systems are guard rails made from steel. Concrete barriers are also in use. All the systems are described in a technical regulation [1]. The systems have to meet test criteria described in DIN EN 1317 [2]. The protection systems and the corresponding regulations were originally developed to protect occupants of cars and/or trucks – but not to protect impacting motorcyclists.

A similar situation exists in Australia. AS3845 [3], AS 1742.3 [4] and AS 5100.2 [5] are the standards that specify how permanent and/or temporary barriers are to be designed, used or tested for roadside and bridge barrier systems. Each State regulatory authority also has its own road design guidelines that further complicate barrier specifications. Whilst AS3845 discusses and considers impacts by motorcyclists, there are no references to any barrier systems specifically designed for protecting motorcyclists.

Some motorcycle rider crashes into steel guard rails, wire rope and concrete barriers have been identified as resulting in severe injuries and hence has become a subject of road safety research.

The German Federal Highway Research Institute (BASt) requested DEKRA Accident Research to analyse real-world crashes involving motorcycles impacting road side barriers and identify typical crash characteristics for further full-scale crash tests using the mostly involved conventional steel-made systems and a concrete barrier (see Figure 1.).

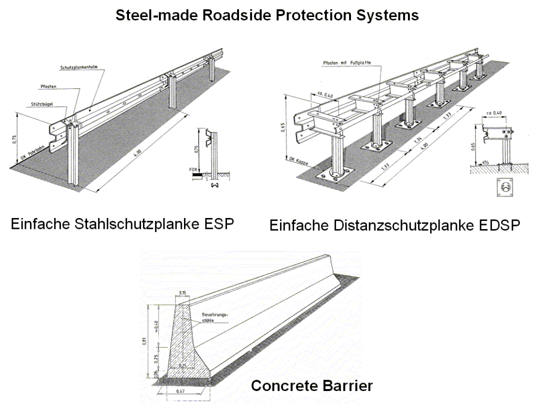


Figure 1. Two steel-guard rails and a concrete barrier common for German roads and investigated with full-scale crash tests

REAL-WORLD CRASHES

There are no federal statistics available for Germany identifying accidents related to motorcyclists impacting a roadside protection system. Forke [6] analysed detailed accident data from France and Austria. He predicted that 4.7% of all crashes involving injured motorcycle riders is related to impacts onto a roadside protection system. This indicates around 1,808 crashes occur where motorcycle riders are injured, can be estimated for Germany in the year 2003 (4.7% of all 38,464 crashes involving injured motorcycle riders registered for this year).

To calculate the total number of accidents where motorcycle riders are killed, Forke uses again French and Austrian accident data and also German data collected from a region around the city of Tübingen. He calculated such crashes to contribute 9.75 to 15% of all fatal crashes. This is around 92 to 114 accidents where motorcyclists are killed for the year 2003 in Germany that are related to impacts onto roadside protection systems (9.75 to 15% of all 38,464 crashes with injured motor-cyclists for this year).

The DEKRA Accident Research Unit analysed 57 real-world crashes involving impacts of motorcycle, and respectively the rider, onto a roadside protection system.

An example of a real-world crash is given in Figure 2. The motorcycle was driven around a left-hand bend. Its speed was reconstructed to be in the range of 85 – 95 km/h. The driver lost control and the motorcycle tilted onto its side. This was followed by an impact of the motorcycle with the rider sliding on the road surface onto the roadside protection system. The protection system is a so called "einfache Schutzplanke" ESP (see_Figure 1.). The profile of its posts is similar to the Greek letter Σ (Sigma). Therefore the post is called a "Sigma Post". The rider's neck directly impacted the post. It is reported that he suffered severe injures (AIS 5) such that his neck was broken directly underneath neck vertebra C1. He also suffered internal injuries from additional impacts. The motorcyclist died after the accident.

63% of the 57 cases analysed by DEKRA involved a steel barrier "Einfache Stahlschutzplanke" ESP (Figure 1.). The second most frequently struck barrier, comprising 18% of all such crashes was another steel-made system, the so called "Einfache Distanzschutzplanke" EDSP (Figure 1.).

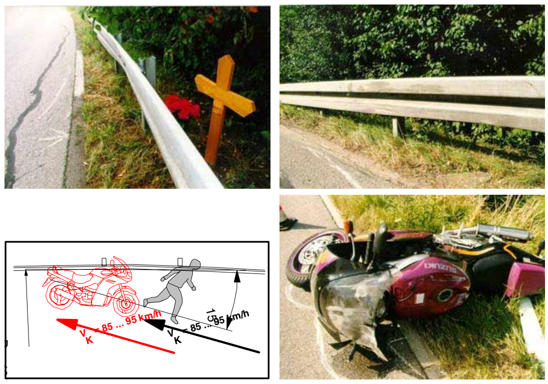


Figure 2. Example of a real-world crash

The DEKRA study also showed that in 51 % of the 57 cases analysed the motorcycle impacted the barrier while driving in an upright position whereas 45% of the impacts occurred where the motorcycle slid on its side on the road surface before it first struck the barrier. In 4% of the crashes the motorcycle impacted the barrier driving in an inclined position (not completely over on its side). In regards to road geometry, 53% being the majority of the crashes occurred in left-hand bends, 50% occurred on straight roads and 7% in right-hand bends.

CRASH TESTS AND RESULTS

Two impact scenarios were chosen for the full-scale crash test program as a result of the findings from the real-world crash study. In the first impact scenario the motorcycle was driven in an upright position (Figure 3) prior to impact. In the other scenario the motorcycle struck the barrier while skidding on its side (Figure 4).

For all crash tests the pre-crash velocity of the motorcycle was 60 km/h. For the impacts where the motorcycle was driven upright the angle between its velocity vector and the barrier was 12°. For the impacts where the motorcycle skidded on the ground the angle between its velocity vector and the barrier was 25°.

All tests were carried out with the same make, model and type of motorcycle being a Kawasaki ER 5 Twister (Figure 5.). The mass of the motorcycle itself was approx. 180 kg and approx. 272 kg with the dummy sitting on the motorcycle and wearing standard protective clothing.

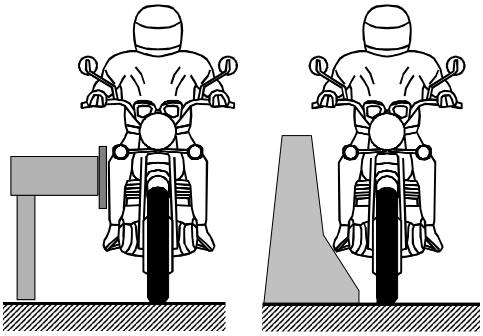


Figure 3. Test where the motorcycle impacted the barrier in an upright driving position

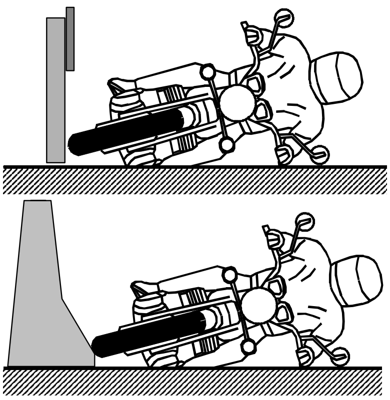


Figure 4. Test where the motorcycle impacted the barrier skidding on its side

Figure 5. Motorcycle Kawasaki ER 5 Twister as used for all crash tests

The Motorcycle rider was represented by a Hybrid III dummy (50th percentile male, hip the same as for a "standing ATD"). To evaluate the injury risk of the rider, the rider's initial contact "primary" impact into the roadside protection system, the "secondary" impact onto the ground and the movement alongside the roadside protection system were assessed using measured dummy loads and by analysing high speed films.

Impacts with the motorcycle moving in upward driving condition

<u>Steel Guard Rail</u>

Figure 6 shows the test with the motorcycle leaving the sled at 60 km/h and impacting at 58 km/h in an upright position the so called "Einfache Distanz-schutzplanke" EDSP.

Figure 6. Full-scale crash test where the motorcycle impacted the steel guard rail "Einfache Distanzschutzplanke" EDSP in an upright position

During this test the dummy slides alongside and onto the steel guard rail. Here, the rider would have suffered severe injuries especially to the shoulder, the chest and the pelvis corresponding to aggressive contacts and snagging with some of the roadside protection system's stiff parts and open profiles.

Figure 7 further illustrates the movement trajectories of the motorcycle and the rider determined from analysis from the films of the overhead-view cameras for a time period of 300 milliseconds after impact into the guard rail. The motorcycle reaches its final rest position 28 m after the point of first contact with the barrier. The distance between the point of first contact and the final rest position of the dummy was 21 m.

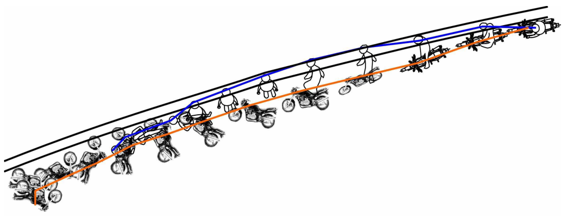


Figure 7. Trajectory of the motorcycle and rider during the first 300 milliseconds after impacting the steal guard rail system EDSP (see Figure 6) determined from analysis of the overhead-view cameras

Measured dummy loads for the head, the chest, the pelvis and the femur corresponding to the moment of first “primary” impact into the guard rail and the “secondary” impact onto the road surface are shown in Table 1. These measurements do not indicate a high-level injury risk. The compressive force of the right femur during the primary impact of 2.6 kN is somewhat high but clearly beneath the limit of 10 kN.

Table 1. Measured dummy loads for the full-scale crash test shown in Figure 6

Dummy load	Primary impact	Secondary impact	Biomechanical limit
Head HIC	4	277	1,000
Head a_{3ms}	9 g	74 g	80 g
Chest a_{3ms}	13 g	n. a.	60 g
Pelvis a_{3ms}	7 g	10 g	60 g
Femur F_{left}	0 kN	4.1 kN	10 kN
Femur F_{right}	2.6 kN	0.2 kN	10 kN

Concrete barrier

The concrete barrier (Figure 8) does not have any aggressive open shaped parts as in the case of the steel-based systems. In this crash test the motorcycle left the sled at 60 km/h prior to impacting the barrier. This was followed by the dummy flying over the top of the barrier. The dummy reached its final rest position on the opposite side of the barrier (Figure 8 and Figure 9). The distance of the final rest position from the point of first contact primary impact location was 26 m for the dummy and 38 m for the motorcycle.

Figure 8. Full-scale crash test of a motorcycle impacting a concrete barrier protection system in an upright position prior to impact moving

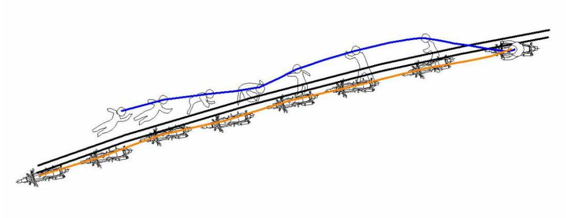


Figure 9. Motorcycle and rider trajectories during the first 175 milliseconds after impacting the concrete barrier (Figure 8) as determined from analysis of the overhead-view cameras

Table 2. Measured dummy loads for the full-scale test shown in Figure 8

Dummy load	Primary impact	Secondary impact	Biomechanical limit
Head HIC	0	164	1,000
Head a_{3ms}	3 g	47 g	80 g
Chest a_{3ms}	4 g	20 g	60 g
Pelvis a_{3ms}	11 g	29 g	60 g
Femur F_{left}	0 kN	0.6 kN	10 kN
Femur F_{right}	4.5 kN	0.1 kN	10 kN

The measured dummy loads again do not indicate any life-threatening injury risk (see Table 2.). The right femur is subjected to a compressive load of 4.5 kN being clearly below the injury limit of 10 kN.

Analysis of the film revealed that the motorcycle and the rider were effectively not decelerated during contact with the concrete barrier. As a consequence of this the risk of being deflected by the barrier into oncoming-traffic on the road is clearly higher than for a barrier protection system made from steel. Another disadvantage of concrete barriers is that during an impact they do not dissipate as much kinetic energy via deformation as the systems made from steel.

Impacts where the motorcycle slides on its side

Steel Guard Rail

Figure 10 shows the test where the motorcycle slides-on its side and impacting the so called "einfache Schutzplanke" ESP (Figure 1).

Figure 10. Full-scale crash test where-the motorcycle impacts the protection system "Einfache Stahlschutzplanke" ESP by sliding into the barrier

The motocycle's velocity leaving the sled was 60 km/h. It directly impacted a sigma post at 47 km/h that broke and was bent down to the ground. Immediately after this first primary impact the motorcycle was stopped and remained stuck underneath the guard rail. The dummy separated from the motorcycle and collided with a sigma post. The distance between the location of the primary impact point and the final rest position was 2 m for the motorcycle and 5 m for the dummy.

Figure 11 shows the trajectories of the motorcycle and dummy before and after impact onto the protection system as determined from the analysis of the film from the overhead-view cameras.

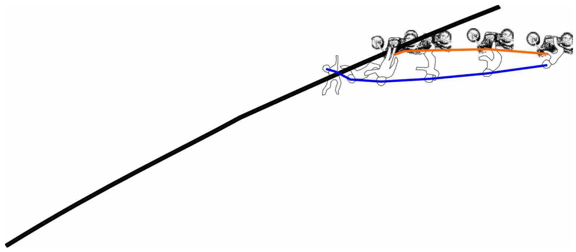


Figure 11. Trajectories determined from the overhead-view cameras of the motorcycle and the dummy before and after impacting the steal guard rail (Figure 10)

Table 3 gives an overview of some of the dummy loads measured at the point of first impact onto the protection system and from the second impact onto the ground. Very high loads above the biomechanical limits were measured for the head during the first contact primary impact. Due to the hard impact into the post, the left shoulder joint of the dummy was broken.

Table 3. Measured dummy loads for the full-scale test shown in Figure 10

Dummy load	Primary impact	Secondary impact	Biomechanical limit
Head HIC	1,074	66	1,000
Head a_{3ms}	125 g	28 g	80 g
Chest a_{3ms}	39 g	39 g	60 g
Pelvis a_{3ms}	15 g	57 g	60 g
Femur F_{left}	3.4 kN	1.2 kN	10 kN
Femur F_{right}	0.5 kN	2.4 kN	10 kN

Concrete barrier

The impact where the motorcycle slides onto its side into the concrete barrier is shown in Figure 12. The motorcycle left the sled at 59 km/h and the front wheel impacted the barrier at 46 km/h.

The trajectories resulting from the analysis of the films from the overhead-view cameras are shown in Figure 13.

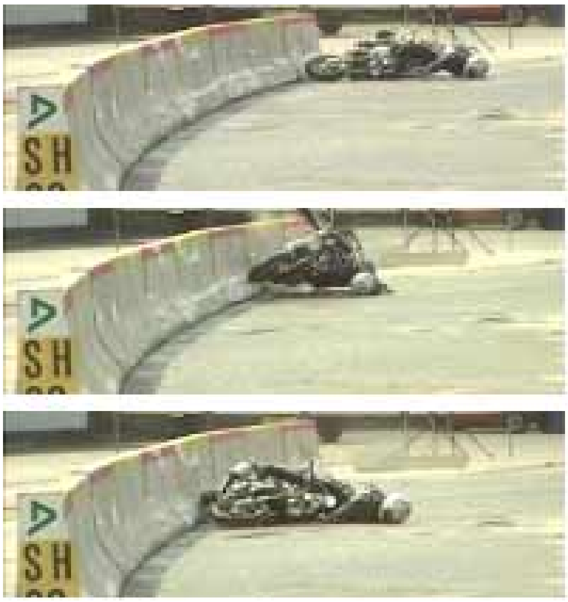


Figure 12. Full-scale crash test where the motorcycle impacts the concrete barrier protection system in a sliding position

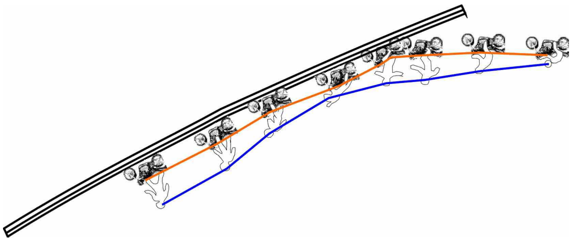


Figure 13. Overhead-view film analysis of test shown in Figure 12 showing the movement of the motorcycle and the dummy before and after impacting the concrete barrier protection system

Table 4. Measured dummy loads for the full-scale test shown in Figure 12.

Dummy load	Primary impact	Secondary impact	Biomechanical limit
Head HIC	1,346	1	1,000
Head a_{3ms}	135 g	8 g	80 g
Chest a_{3ms}	50 g	4 g	60 g
Pelvis a_{3ms}	16 g	4 g	60 g
Femur F_{left}	4.1 kN	3.0 kN	10 kN
Femur F_{right}	1.6 kN	0 kN	10 kN

Some of the measured dummy loads related to the point of first impact into the protection system and to the second impact onto the ground are shown in table 4.

Deceleration of the motorcycle and dummy were not as rapid as during the impact where the motorcycle slid into the guard rail made from steel. Nevertheless the measured dummy decelerations for the primary impact were high, indicating a ~~risks~~ of severe and life-threatening injuries. The dummy head loads again lay clearly above the corresponding biomechanical limits.

Impacts into a modified steel guard rail system

The analysis of real-world crashes and the results of the crash tests shown above provided the technical basis to improve conventional roadside barriers made from steel with respect to protecting motorcyclists. As a first attempt a modified protection system was proposed and tested.

Figure 14 provides some information in regards to structure and the geometry of the modified system. The system is a so called “Schweizer Kastenprofil” consisting of sigma posts and a closed box-shaped profile at the top. An additional underrun protection board was mounted near to the ground to prevent both the direct impact onto a post and movement of the motorcyclist underneath the barrier protection system.

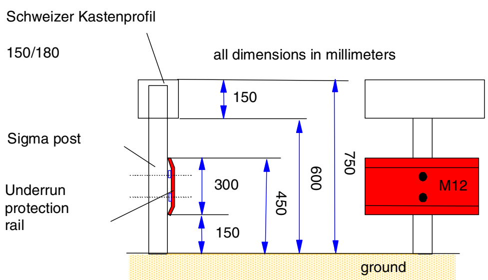


Figure 14. Modified guard rail system with respect to better protection for impacting motorcyclists

Two additional full-scale crash tests were carried out to analyse the behaviour of this modified roadside protection system where the rider was in the upright-impact position and a scenario where the impacting motorcycle and rider were sliding on the road surface.

Impact where the motorcycle-is in an upright position

Figure 15 shows the crash test where the motorcycle and dummy is moving upright at 60 km/h and impacting the modified steel guard rail barrier system at 12°. After first contact into the barrier the motorcycle was redirected away from the barrier. The dummy separated from the motorcycle and fell onto the protection system. After sliding for a short distance on the guard rail the dummy fell to the ground on the opposite side. Because of the closed shape of the box-type profile, snagging did not occur and injury risk from impact was low as observed from the analysis of the film.

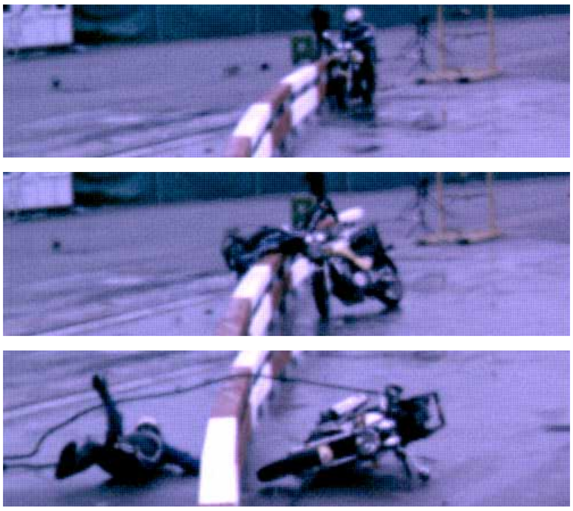


Figure 15. Full-scale crash test where the motorcycle impacts the modified steel guard rail system in an upright position

The trajectories of the motorcycle and dummy before and after impact onto the protection system determined from the analysis of the film from the overhead-view cameras is shown in Figure 16. The characteristics of the trajectories are similar to the corresponding crash test onto the concrete barrier (compare Figure 8 and Figure 9 to Figure 15 and Figure 16). The motorcycle reached the final rest position 23 m after initial contact primary impact. In the case of the dummy, the distance between the location of the initial primary impact and the final rest position was measured as 22 m.

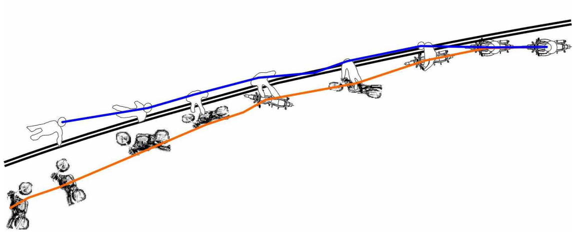


Figure 16. Trajectories of the motorcycle and dummy determined from the overhead view camera before and 230 milliseconds after impacting the modified steel guard rail system (see Figure 15)

Measured dummy loads related to the initial primary impact into the protection system and to the secondary impact onto the ground are shown in Table 5. Except for the left and right femur all measured loads of the other body parts are low and clearly beneath the corresponding biomechanical limits.

A compressive force of 6.3 kN for the right femur during the primary impact, 9.3 kN for the left femur and 6.5 kN for the right femur during the secondary impact, were markedly higher - compared to the corresponding results of the tests involving the concrete barrier and the unmodified steel guard. Even though this result was disappointing it could also be interpreted as an example of a worst-case condition. For instance, it was observed from the film sequences that the secondary impact of the dummy onto the ground occurred such that both legs initially struck the ground at the same time resulting in relatively high deceleration of the torso.

Table 5. Measured dummy loads for the full-scale test shown in Figure 15.

Dummy load	Primary impact	Secondary impact	Biomechanical limit
Head HIC	1	103	1,000
Head a_{3ms}	3 g	36 g	80 g
Chest a_{3ms}	3 g	17 g	60 g
Pelvis a_{3ms}	9 g	11 g	60 g
Femur F_{left}	0 kN	9.3 kN	10 kN
Femur F_{right}	6.0 kN	6.5 kN	10 kN

Impact where the motorcycle slides into the barrier

Figure 17 shows the crash test where the motorcycle and dummy slides on the road surface. The motorcycle left the sled at 60 km/h and impacted the barrier at 54 km/h. Due to the impact the underrun protection board broke and the motorcycle struck a Sigma post. The dummy separated from the motorcycle immediately after the initial primary impact and then the helmeted head struck the underrun protection board.

Figure 17. Full-scale crash test where the sliding motorcycle impacted the modified steel guard rail system

The trajectories of the motorcycle and dummy before and after the impact into the protection system determined from the analysis of the film from the overhead-view cameras is shown in Figure 18. The distance between the location of the initial primary impact and the final rest position is 1 m for the motorcycle and 7 m for the dummy.

Table 6 gives an overview of measured dummy loads related to the primary impact and to the secondary impact. For the primary impact into the protection system all measured dummy loads were clearly less than their corresponding injury tolerance limits. However the measured 3-ms-96 g head acceleration during the secondary impact is above the tolerance limit of 80 g. Also the HIC in the secondary impact with a value of 510 but clearly beneath the limit of 1,000 is relatively severe.

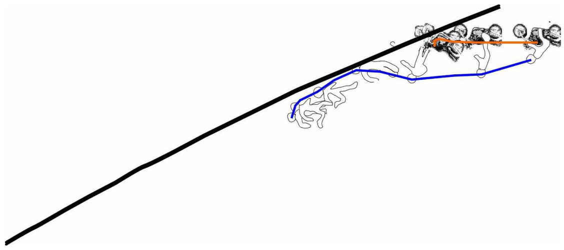


Figure 18. Trajectories of the sliding motorcycle and dummy determined from the overhead view camera before and after impacting into the modified steel guard rail system (see Figure 17)

Table 6. Measured dummy loads for the full-scale test shown in Figure 17

Dummy load	Primary impact	Secondary impact	Biomechanical limit
Head HIC	83	510	1,000
Head a_{3ms}	43 g	96 g	80 g
Chest a_{3ms}	10 g	31 g	60 g
Pelvis a_{3ms}	11 g	19 g	60 g
Femur F_{left}	0.9 kN	3.7 kN	10 kN
Femur F_{right}	3.6 kN	0.4 kN	10 kN

In summary, the results from the crash tests show that the risk of injury for a motorcycle rider is much lower when impacting the modified system. The additional underrun protection board eliminated snagging of any parts of the impacting dummy. The additional board also absorbed kinetic energy as a result of its deforming during impact. However, the motorcycle was not redirected away from the protection system after initial impact. Hence, further improvements are still necessary to ensure the underrun protection board does not break and that the severity of the secondary impact onto the ground is reduced. Further questions arise whether the biofidelity of the Dummy Hybrid III is sufficient to accurately predict all injury risks a motorcyclist may be exposed to when impacting a roadside protection system and any subsequent impacts onto the road surface.

NUMERICAL SIMULATIONS

Monash University's Department of Civil Engineering has also carried out computer simulations to investigate motorcycle impacts into roadside barriers. The DEKRA results from the crash test, where the upright motorcycle impacts the concrete barrier, were used to validate a MADYMO motorcycle-barrier model. This model was then used to investigate other impact speeds, a 25° impact angle scenario and different impact scenarios between an upright motorcycle and a wire rope barrier system.

MADYMO Models

The MADYMO model consisted of four distinct systems; the road, the motorbike, the barrier and the rider. Two barrier types were modelled namely a concrete barrier and a wire rope barrier.

The road was assigned as the inertial space on which the motorbike, barrier and rider operated.

The motorcycle model with an adult male rider is shown in Figure 19. It represents a typical road motorbike with a dry weight of 240 kg.

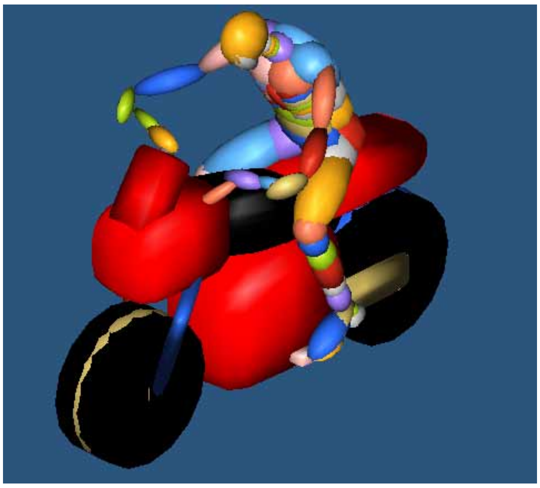


Figure 19 MADYMO motorcycle model

The stiffness properties for the wheels, engine, steel and fibreglass chassis used for the motorcycle model were selected based on previous experimentally validated crashworthiness studies of a variety of vehicles carried out by Zou and Grzebieta. Because the motorcycle was constructed as a multi-body system, parts of the motorbike surface area had to be constructed in such a way as to be able to interact with the concrete barrier, the wire rope barrier and the road surface.

The concrete barrier was modelled using a single ellipsoid with a height of 800 mm, a width of 200 mm and a length of 10 m. The barriers weight was based on a material density of 2,500 kg/m^3 and hence was assigned a very high stiffness function so that there was minimal defection of the barrier during the simulations.

The wire rope barrier model was based on an actual installed system (Figure 20 and Figure 21). This barrier consisted of seven posts that supported the four wires of the barrier. The wires of the barrier that were modelled are made up of three high tensile steel cables woven together with an assumed yield stress of 500 MPa. They have a combined circumference of 60 mm and were represented in the model by a TRUSS2 finite element with a cross sectional area of 280 mm^2 for each cable. The wires had an initial tension setting of 5 kN. Ellipsoids were used to model the support posts being 2 mm thick.

A non-helmeted 50th percentile adult male Hybrid III MADYMO model was used for the rider. The rider's seated position on the motorcycle is shown in Figure 19. The crash scenario where the rider was seated in an upright position was the only scenario analysed for the MADYMO model. Similarly only maximum value chest and head injuries were calculated and are listed here. No distinction was made between a primary or secondary impact.

Figure 20 Four rope wire rope barrier

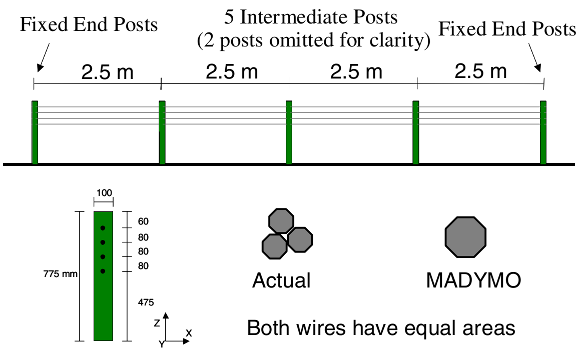
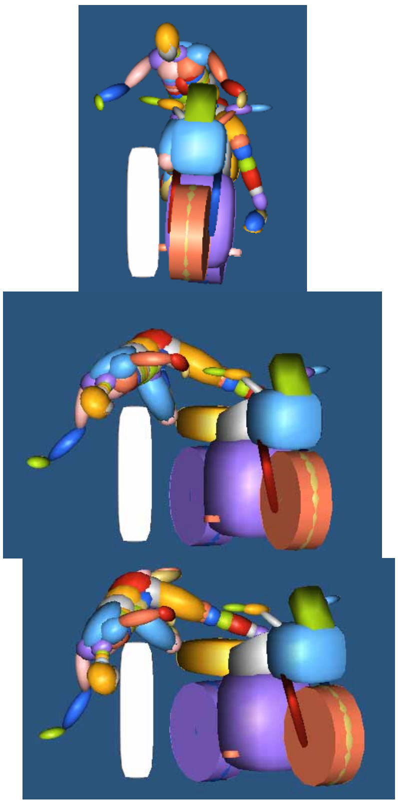


Figure 21 Wire rope barrier simulated in MADYMO

Simulation Results

<u>Concrete barrier</u>

Table 7 shows the resultant injury criteria from the DEKRA crash test compared to the MADYMO simulation where the rider impacts the concrete barrier in an upright position. Impact kinematics for an upright motorcycle with a rider impacting the concrete barrier are shown in Figure 22. The rider kinematics when compared to Figure 8 look similar. However the motorcycle seems to rebound from the wall, indicating further refinement of the model is required if it is to accurately model the actual crash test.



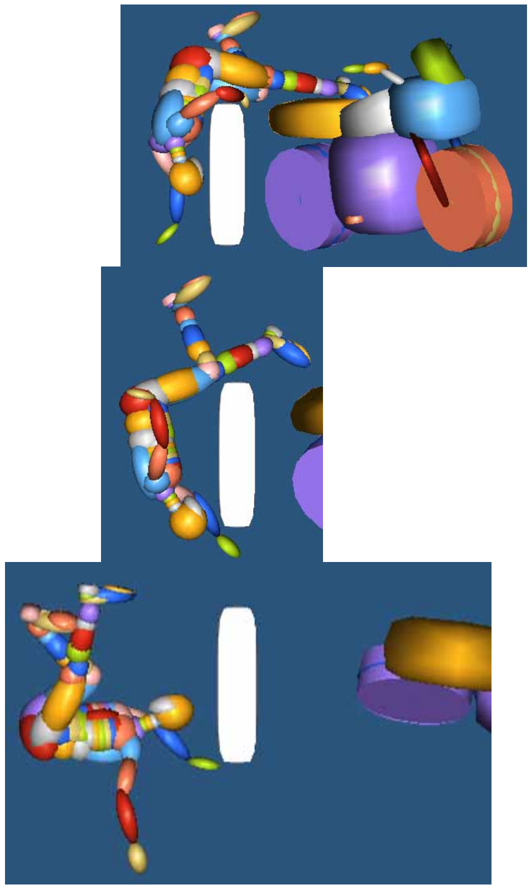


Figure 22 MADYMO simulation showing an upright seated rider on a motorcycle crashing into a concrete barrier at 60 kph and 12º

At a shallow impact angle (12º) the resulting calculated injury for the head and chest indicate that some form of injury is probable but is below threshold limits.

In each simulation the dynamics of the rider's fall to the ground were different. Consequently each simulation produces different injury values. For example in the 25º collision at 80 km/h the rider does a full vault landing feet first rather than head first. Hence a slightly lower HIC value is obtained when compared to the slower speed collision at the same angle.

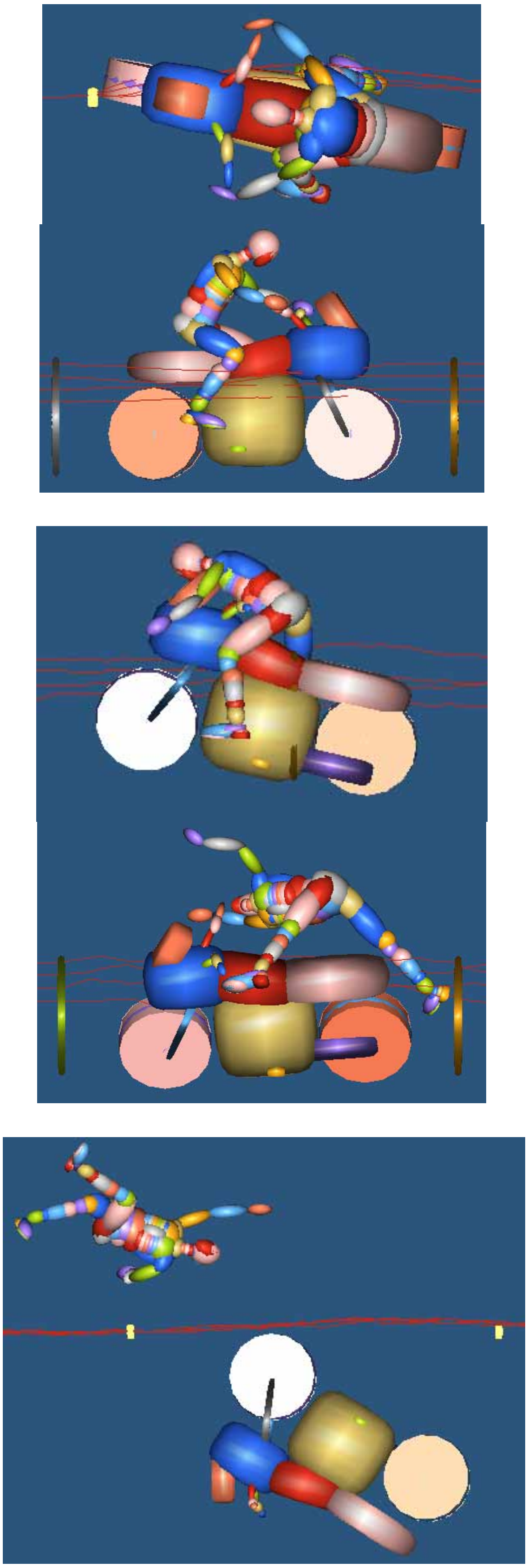


Figure 23 MADYMO simulation showing an upright seated rider on a motorcycle crashing into a wire rope barrier at 60 km/h and 12º

Table 7. Measured dummy loads for the full-scale test shown in Figure 17

Simulation	Speed km/h	HIC 36ms	Chest g
DEKRA test	**60**		
(primary impact)		0	4
(secondary impact)		164	20
12º Concrete barrier	**60**	44	15
	80	39	23
25º Concrete barrier	**60**	133	32
	80	100	20
12º Wire rope	**60**	462	68
	80	1205	100
25º Wire rope	**60**	3,478	144
	80	4,879	41
Injury criteria for a 50% male		**1000**	**60g**

Wire rope barrier

Figure 23 shows the kinematics for an upright rider on a motorcycle impacting a wire rope barrier. The calculated injuries from the simulations suggest that serious injury would result regardless of speed and impact angle.

In all simulations the motorcycle slides along the wires until it hits a post, squeezing and trapping the rider's leg against the wires as it does so. The post contact causes the motorcycle's front wheel to snag lifting the front of the motorcycle up and throwing the rider's torso and head forward. Because the rider's leg is trapped between the motorcycle and the wire ropes and the foot snags in the ropes, the head and torso slap into the front of the rising motorcycle. Eventually the leg becomes free as the motorcycle rotates and the rider is then catapulted over the barrier. This is a different result to the concrete barrier where the rider was thrown over the barrier with relatively little snagging or deceleration.

In both the 60 km/h and 80 km/h impact speeds at an angle of 25º, the motorbike throws the rider into the air with the rider hitting the ground head first. Hence the high HIC.

One of the motorcycling community's key concerns with wire rope barriers was the possibility of a rider's limb(s) becoming caught in the barrier during a collision. The simulations seem to indicate that this snagging effect occurs for both the rider's leg nearest the barrier. However of greater concern is the snagging of the motorcycle's front wheel on the barrier's posts.

Discussion

Concerns have been raised by the motorcycling community about potential injuries resulting from collisions between motorcycles and wire rope barriers. To date little research has been undertaken to confirm or deny any concerns.

The concrete barrier simulations seem to indicate that a motorcyclist impacting such a barrier in an upright position will sustain survivable injuries because of low decelerations during impact. However, the motorcyclist is exposed to considerable risk when catapulted over the barrier into the hazard being protected by the barrier, particularly if it is a median barrier and there is oncoming traffic on the other side.

Simulations of the wire rope barrier collisions showed that regardless of angle or speed it is unlikely that the motorcyclist will clear the barrier very cleanly. In many cases the motorcyclist's extremities became caught between the wires. This results in the rider being subjected to high decelerations and possible high injury risk secondary impacts into the road.

In all the simulated wire rope barrier collisions, the wires guided the motorcycle into the posts leading to heavy contact with the post. The motorcycle and the rider were subjected to large decelerations because of this snagging effect and hence elevating the injury risk for the rider.

While the simulations in this report are preliminary, and work is continuing to refine the MADYMO models and calibrate them against the DEKRA tests, they show that the risk of injury to a motorcyclist colliding with either a wire rope or a concrete barrier will be high. The findings also suggest that while the current design of flexible barriers has safety advantages over concrete barriers for passenger vehicles, the opposite may be true for motorcyclists. Most of all, it has highlighted the need for further research into the area of motorcycle collisions with various crash barriers.

SUMMARY AND FUTURE WORK

Vehicle safety is still a major area of applied research, technical development and engineering. Large gains have been achieved in regard to the long-term reduction of road users killed and severely injured over two decades now. But further efforts are necessary to maintain the continual reduction of the "road toll" cost paid every year as a consequence of modern societies demand for mobility and transport on our roads.

From a political perspective example target objectives are outlined in the Commission of the European Community's White Paper "European Transport Policy for 2010: Time to Decide" and in the "Vision Zero" legislation adopted by the Swedish Government. Common research objectives following an integrated holistic systems approach may provide the best potential to explore new options and/or better transform known solutions to improve vehicle and road safety in relation to the interaction between man, machine and infrastructure as a whole. The primary safety of vehicles has offered new perspectives but secondary safety seems to be offering further substantial gains in reducing road carnage.

In this context the safety of motorcyclists is also of interest. There are safety system options available and elements that can be fitted to motorcycles to improve their secondary safety. But the secondary safety of vehicles - and especially of motorcycles does not depend entirely on the crashworthiness performance of the vehicle itself.

Additional safety measures can be addressed by an actual research field called "compatibility". Compatibility currently only addresses the interaction of two vehicles crashing into each other and the balancing of self protection and partner protection seen as an integrated optimum. For secondary motorcycle safety the car's crashworthiness is very important as the most frequent crash partner in a motorcycle crash. However, the infrastructure, being compatible with cars, also needs to be considered in relation to motorcycle secondary "compatible" safety. As shown in the paper, research and engineering work dealing with motorcycle impacts onto roadside protection systems is another field of research where the secondary safety of motorcycle riders can be improved.

Last but not least there are some more options where motorcycle rider crashworthiness can be improved by further improving their clothing. Not only is the behaviour of helmets, jackets and trousers, under isolated test conditions to assess and improve the damping and/or abrasion resistance of interest, but there is also an integrated approach possible with additional improvements of the performance of safety elements and systems fitted to the motorcycle itself and to the motorcycle rider's clothing in relation to barrier impacts.

Not only should research continue into improving the crashworthiness of car and truck roadside barrier impacts but research into improving motorcycle rider impact crashworthiness should also be considered. The research program presented in this paper will continue both in regards to experimental testing either in Germany or Australia and in regards to computer simulations to improve models so that novel crashworthy designs to reduce motorcycle injuries can be investigated.

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EXPLORATORY STUDY OF AN AIRBAG CONCEPT FOR A LARGE TOURING MOTORCYCLE : FURTHER RESEARCH SECOND REPORT

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ABSTRACT

Honda has been conducting feasibility research for airbags mounted on a motorcycle. The concept of this airbag system is "To reduce the injuries to a rider when impacting with an opposing vehicle and/or opposing object in frontal collisions by absorbing rider kinetic energy and by reducing rider separation velocity from motorcycle in the forward direction." The study was reported to the 16th ESV Conference in 1998 and the 17th ESV conference in 2001. However, the assessment of injury level using dummies was tentative, as the assessment method on the neck was not firmly established in ISO 13232.

Reporting is made this time on the results of 12 cases of full scale impact tests in seven configurations based on ISO/CD 13232, which established the assessment method of injury to the neck, and on the results of computer simulation of 200 configurations, which calculate the process of dummies falling down to the ground.

The base motorcycle on which the prototype airbag system was mounted for this study, the GL1800, is a model which succeeded the large touring motorcycle, GL1500, used in the previous studies.

Furthermore, to grasp the effectiveness of an airbag in reducing injury potential, while minimizing the potential for inflicting injury, in addition to the assessment tests specified in ISO/CD 13232, full scale impact tests of other configurations and other rider conditions, as well as sled tests were conducted.

It was judged from the results obtained that an airbag system for a large touring motorcycle is feasible.

INTRODUCTION

Honda has been engaged in research aimed at enhancing protection of motorcycle riders since the 1960s [1]. In recent years, a study designed to evaluate the possibility of installing airbags on motorcycles as a means of enhancing motorcycle rider protection during frontal collisions has been conducted. The concept is "To reduce the injuries to a rider when impacting with an opposing vehicle and/or opposing object in frontal collisions by absorbing rider kinetic energy and by reducing rider separation velocity from motorcycle in the forward direction". The research for the airbag system for motorcycles has been conducted heretofore in the manner as outlined below:

A prototype airbag system including a sensor system was mounted on a large touring motorcycle, GL1500, and evaluated based on ISO 13232 - Test and Analysis Procedures for Research Evaluation of Rider Crash Protective Devices Fitted to Motorcycles [2]. As the result of a series of impact tests using actual motorcycles (hereinafter referred to as full scale impact tests) and computer simulation, the possibility of an increase in injury potential was noted in some impact configurations, while the overall effect of rider injury reduction seemed likely [3](ESV paper in 1998).

An effort was made to establish a solution for the apprehended phenomenon of increase in injury, that is, the injury on the neck at dummy/ground contact influenced by the airbag. Enlarging the airbag minimized the concern [4] (ESV paper in 2001).

Because many of the differences in injuries with or without the airbags occurred at dummy/ground contact, computer simulation technology was desired to cover that area. As a result of addressing this issue, a simulation technology was developed, which will reproduce with high precision motion at dummy/ground contact [5] (SETC paper, 2003).

As a link between these research projects, full scale impact tests were carried out with a prototype airbag system on a large scooter type motorcycle which uses a different frame design than the large touring motorcycle, using part of ISO 13232. It was judged that an airbag employing the same design concepts as that for large touring motorcycles was potentially feasible for use in the large scooter type motorcycles[6] (IFZ paper, 2004).

While these research projects pertaining to the feasibility of using airbags on motorcycles were being conducted, the method of assessing the level of injury on the neck, which had not been established previously, was established by ISO/CD 13232. Additionally, a simulation technology was obtained by Honda, which enabled researchers to assess the level of injury sustained at the time of dummy/ground contact. These advances enabled researchers to more comprehensively evaluate rider protective devices.

This report will present a series of results from the evaluation of the airbag system for motorcycles, based on the established evaluation methods. For the base motorcycle to mount the airbag, the GL1800 was used, which succeeded the large touring model GL1500 used in the previous research. To further clarify the injury reduction effectiveness as well as the reduction of airbag induced injuries, tests were conducted employing other impact configurations and other rider conditions, in addition to the assessment tests specified in ISO/CD 13232.

CONCEPT OF HONDA AIRBAGS FOR LARGE TOURING MOTORCYCLES

The results of an analysis of fatal accidents to motorcycle riders in Japan are shown in Fig.1[7]. These results indicate that:

- fatal injuries occur mostly (i.e.. 64 percent) during motorcycle frontal impacts;
- most rider injuries (i.e.. 87 percent) are receiving by impacting against objects other than the motorcycle;
- the most frequently and severely injured body region(i.e.. 87 percent) lies in the upper half of the body.

Based on the accident data, a typical fatal accident scenario involves: an impact at the front of the motorcycle, the rider being ejected from the motorcycle, the rider striking an opposing vehicle or ground and receiving a fatal injury to the upper half of the body. From this information, a concept involving non-ejection or energy reduction of the rider was conceived. Subsequently, Honda studied a motorcycle mounted airbag as one implementation of this concept. The concept of Honda's airbag for motorcycles is:

"To reduce the injuries to a rider when impacting with an opposing vehicle and/or opposing object in frontal collisions by absorbing rider kinetic energy and by reducing rider separation velocity from motorcycle in the forward direction".

Additional factors were also considered, including the following, based on past research:

- The airbag position and horizontal forces being supported by the motorcycle itself (eg, even in front to front impacts with passenger cars the airbag should function without the airbag needing to be in contact with the opposing vehicle)
- Maintaining airbag effectiveness as much as possible during various motorcycle crash motions, especially the yaw, pitch and roll motions which tend to occur during motorcycle collisions.

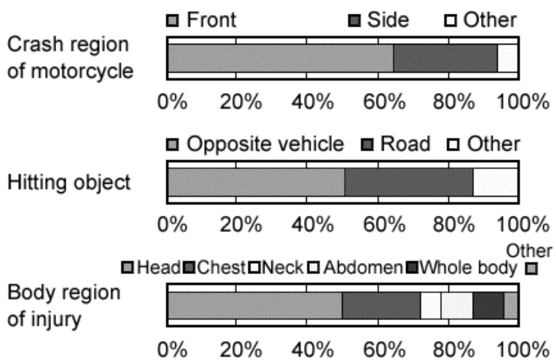


Figure 1. Fatalities of motorcycle accidents in Japan.

TEST MOTORCYCLES MOUNTED WITH PROTOTYPE AIRBAG SYSTEM

Figure 2 shows a test motorcycle equipped with a prototype airbag system. The major specifications of the test motorcycle, the GL 1800, equipped with a prototype airbag system are shown in Table 1: The model has the following features similar to GL1500:

- Having upright riding position, there is a space in front of the rider to deploy an airbag.
- With a low center of gravity and large mass, the motorcycle body will have less pitching and yawing during impact.
- Because the large fairing may receive the collision impact at a higher position than the height of the center of gravity, the body pitching of motorcycle will be lessened during impact.

Figure 3 shows the deployed airbag and Table 2 shows the specifications for the airbag and inflator. The airbag and retainer box were re-designed for the GL 1800 base motorcycle. The results of previous research are reflected in the airbag design; such as a large volume, overall shape well contrived, the shape of the back of bag, which will hold the rider and the support belt connected from the back of bag to the frame of motorcycle. The time required for the deployment of the airbag is approximately 45msec.

A sensor system will judge whether to actuate or not in accordance with the logic shown in Fig. 4 based on the extent of deceleration in the vicinity of the front wheel axis (hereinafter referred to as the deceleration of the front wheel system).

SETTING UP SENSOR SYSTEM

The judgment of whether to deploy or not of the airbag system will be based on the following conditions:

- Deploy in frontal collisions in which rider ejection from the motorcycle is likely.
- Not to deploy as a result of impacts received during typical riding and handling conditions, including operating over rough roads.

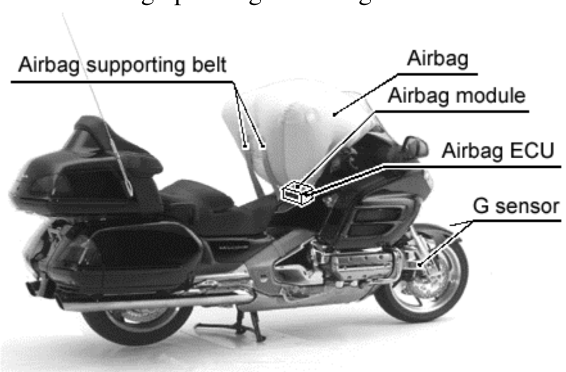


Figure 2. Prototype airbag system installed on the GL 1800 motorcycle.

Table 1.
Specifications of test motorcycle

Manufacturer	Honda
Model	GL1800
Year	2000-2003
Mass (empty, as tested, no airbag)	367 kg (average)
Mass (empty, as tested with airbag)	375 kg (average)
Length, overall	2635 mm
Width, overall	945 mm
Height, overall	1455 mm
Wheelbase	1690 mm
Type	Touring

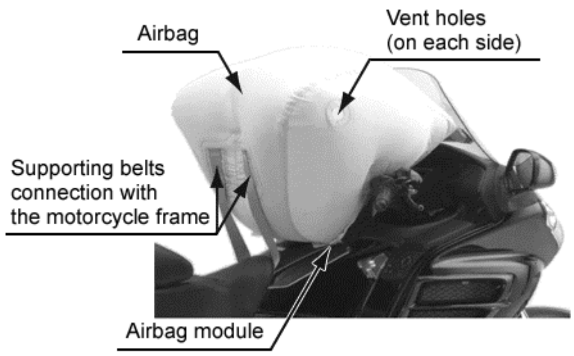


Figure 3. Prototype airbag.

Table 2.
Specifications of prototype airbag

Volume	157 liter (net, inflated)
Height (from the seat) x width x length	750 mm x 720 mm x 640 mm
Vent holes	2 x 45 mm diameter
Rear shape	Forms a concave "V"
Bag mounting	1) to module box 2) to motorcycle frame beneath the seat, via 2 connecting belts
Infrator	Pyrotecnic; Passenger car type; 495 kPa

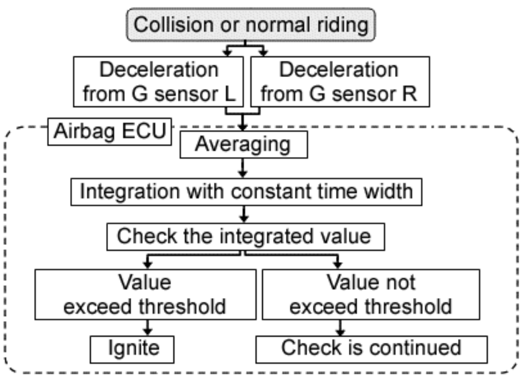


Figure 4. Decision flow for deployment.

Grasping Conditions of Collision to Deploy Airbag

To grasp the conditions of frontal collisions which will cause the forward separation of rider from the motorcycle, impact tests were carried out using the base motorcycle. For the opposing vehicle in the impact testing, the Honda Accord 4-door, 1998~2001 model, of Japanese specifications as shown in Table 3 was used. For the rider dummy, ISO/CD 13232 motorcyclist anthropometric test device (MATD) was used. The impact configurations and test results are shown in Table 4. The forward separation of the dummy occurred at the impact speed of 35km/h, and did not occur at the impact speeds of 25 and 30km/h in both impact configurations to the front and side of opposing vehicle. It was judged from these results that the airbags should deploy at an impact speed of over 35km/h in a frontal impact. The extent of deceleration of the sensor unit was measured in the testing for use as the base data for developing the collision judge logic and the setting of the threshold value as described later.

Grasping Deceleration of Sensor Unit Under Conditions Not to Deploy Airbag

No airbag should deploy during typical running and normal handling, including travel over rough roads, except in the case of an accident. To simulaterunning conditions in which the airbag should not deploy, tests were conducted on running over steps, traveling on roads with depressions, running on rough roads, as well as while performing a “wheelie”. To simulate handling conditions in which the airbag should not deploy, tests were carried out assuming a fall from the platform of a truck while engaged in cargo handling operations and when the front fork receives an impact from an external force. The deceleration of the sensor unit occurring when tested under this variety of running and handling conditions, where the system should not be deployed was measured and used as the base data for creating the collision judge logic and threshold value.

Setting Up Collision Judge Logic and Threshold Value

Collision judge logic and the threshold value for the decision of deployment were decided after studying the data of deceleration of sensor unit, which were grasped from the results of tests under impact conditions to deploy and the conditions of running and handling not to deploy. Figure 5 shows the judgment performance of deployment or no-deployment. The figure shows the ratio of "Threshold value, specified computation value to judge to deploy" over "The maximum computed values for the cases of deployment or no-deployment ". As shown in the figure, a judgment system was obtained, which will deploy in frontal impacts requiring the deployment of an airbag, but not as the result of expected impacts occurring in normal running and handling.

Table 3.
Specifications of Opposing Vehicle

Manufacturer	Honda
Model	Accord, Japan
Year	1998 -2001
Mass	1300 kg (average)
Overall length	4635 mm
Overall width	1695 mm
Overall height	1420 mm
Wheelbase	2665 mm
Engine displacement	1997 cm³

Table 4.
Tests and results to grasp the impact condition that airbag should be deployed

Collision conditions		Dummy motion	Deploy or not
To Accord front	20 (km/h)	No separation from MC	Not necessary
	30 (km/h)	Just before separation from MC	Not necessary
	35 (km/h)	Separated from MC	Necessary
To Accord side	20 (km/h)	No separation from MC	Not necessary
	30 (km/h)	Just before separation from MC	Not necessary
	35 (km/h)	Separated from MC	Necessary

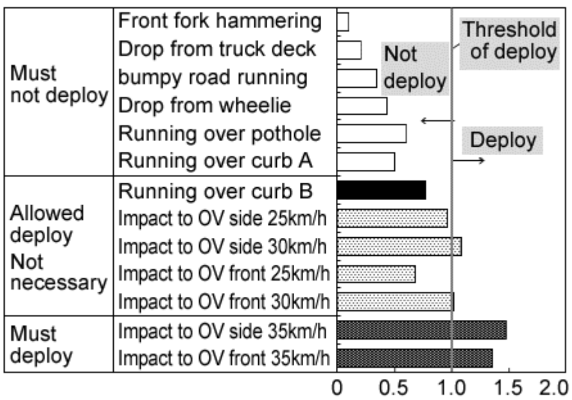


Figure 5. Decision of deployment by integrated impact deceleration.

Features of Collision Judging Sensor System

In the collision judging sensor system, judgment is made upon the extent of deceleration of the front wheel system because it will enable the system to make judgment of deployment at an early time during the crash event. Basically, deployment of the airbag should be completed before the rider reaches the airbag during the collision deceleration of the motorcycle. In a typical motorcycle frontal collision, the front wheel will first contact the opposing vehicle or other object and the deceleration of the sensor and motorcycle frame will occur as shown in the example of Fig.6. As shown in the figure, the extent of deceleration of motorcycle frame is extremely low at the time during which the judgment can be made whether to deploy the airbag using the deceleration of the sensor installed on the front wheel system. Therefore, the judgment of deployment can be made at a faster timing if the deceleration of the front wheel system is used rather than the deceleration of the motorcycle frame.

Also in the sensor system, acceleration sensors are installed on the front forks, both right and left to detect the deceleration of the front wheel system. The sensor system is capable of making appropriate collision judgment based on the deceleration of the front wheel system, computing and judging using the average of detected values by the acceleration sensors on the left and right and removing the influence of the rotary movement of the steering system, which occurs during an angled impact.

FULL SCALE IMPACT TESTS IN ACCORDANCE WITH ISO/CD 13232

Test Method

The airbag system was evaluated in accordance with ISO/CD 13232. With respect to the seven impact configurations shown in Fig. 7, full scale impact tests were carried out using motorcycles equipped with an airbag and those not equipped with an airbag. As described later, in the two configurations of 412-25/50 and 143-35/0, the airbag system was not in operation, and as such no impact test of the base motorcycle was carried out.

For the opposing impact vehicle, the same Honda Accord 4-door of 1998~2001 model of Japanese specifications as used in the impact test for setting sensors was used. This is the opposing impact vehicle conforming to the stipulation of ISO/CD 13232 (Refer to Table 3).

The impact speed in the research was set at a level 4% higher than that specified in ISO/CD 13232 to make the evaluation under stricter conditions. The speed in the parentheses in the figure denotes the speed specified by ISO/CD 13232.

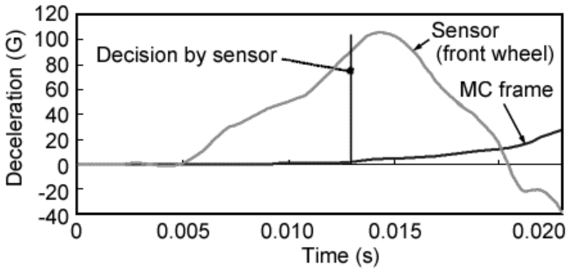


Figure 6. Deceleration of "sensor (front wheel) and motorcycle frame".

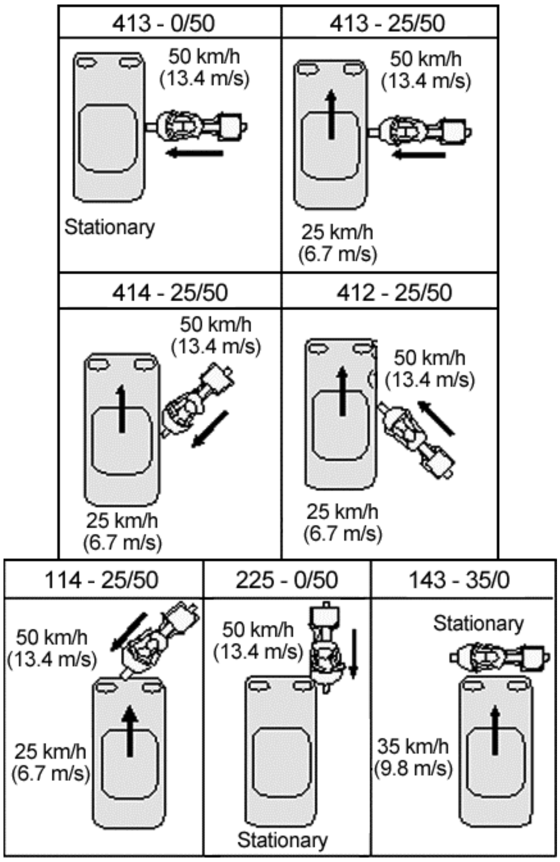


Figure 7. Configurations of full scall impact test.

For the rider dummy, the motorcyclist anthropometric test device (MATD) as defined in ISO/CD 13232 was used. This dummy does not require any connecting cord to the outside, which may affect to the movements of dummy, as an electric measuring and recording system is built inside the dummy. Using the measurement by the dummy and the injury analyzing method shown in ISO/CD 13232, an assessment was made on the level of injuries on head, neck, chest, abdomen and legs.

Test Results

Judgment of Deployment or No-deployment of Airbag, and Judgment Timing

The results of performing impact tests of motorcycles mounted with the airbag system were gathered and analyzed. Out of impact tests conducted in seven configurations the airbags operated in five configurations and were not in operation in two configurations.In the four configurations of 413-0/50, 413-25/50, 414-25/50 and 114-25/50, the deployment of the airbag was finished before the dummy reached the airbag during the crash. This was accomplished by the quick judgment of the sensor system. The judgment timing of sensor system and the time for the dummy to reach the airbag in the four configurations are shown in Fig. 8. As an example of the deployment of the airbag and its effect, Fig. 9 shows the start of impact (t=0), start of airbag deployment (t=20msec), completion of deployment (t=60msec) and nearly finish of the absorption of kinetic energy of dummy (t=120msec) in the case of 413-25/50.

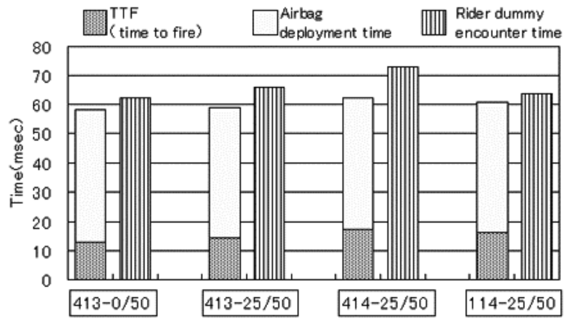


Figure 8. Decision time of airbag deployment from full scall impact tests.

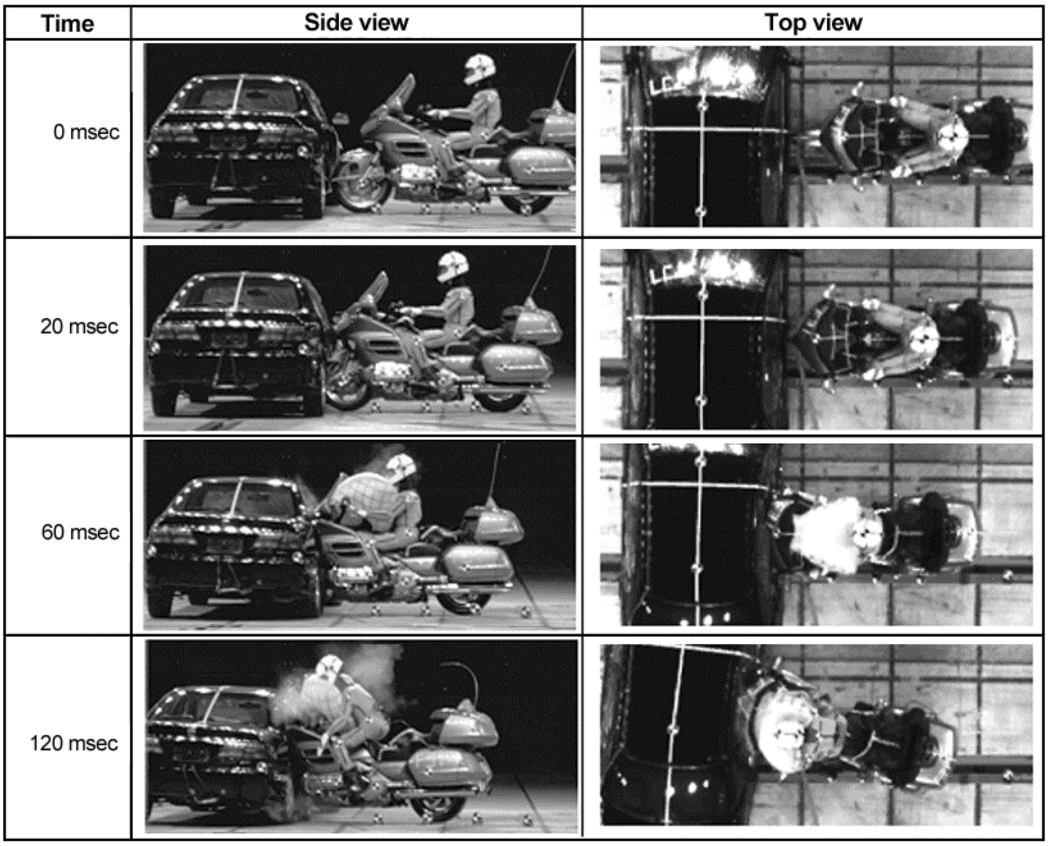


Figure 9. Sample of airbag deployment and effectiveness.

In case of 225-0/50, the dummy contacted the airbag before the deployment was completed. But, the extent of injury resulting from interference with the airbag was not measurable. (Refer to the section dealing with the analysis of injury described later.)

In the two configurations of 412-25/50 and 143-35/0, the airbag was not deployed due to the judgment of no-deployment by the sensor system. In case of 412-25/50, the motorcycle did not decelerate significantly, colliding with the opposing vehicle then diverting its direction along the side of the opposing vehicle. 143-35/0 is not the case of a frontal impact, the objective of the airbag system. It is a configuration in which the motorcycle is collided by an opposing vehicle from its side, an impact in which the airbag should not to be deployed.

Analysis of Injuries

With respect to the indices of injuries in the seven impact configurations, the results of analysis based on ISO/CD 13232 are shown in Table 5 in the changes of AIS (abbreviated injury scale) by body regions and in changes of NIC (normalized injury cost) of the whole integrated body. AIS = 1 is equivalent to light injury while AIS = 6, fatal. NIC = 0 is equivalent to no injury and NIC = 1 fatal. Positive indices show benefits and negative indices show risks. In the two configurations of 412-25/50 and 143-35/0 where the airbags did not deploy, riders sustained no injury from the airbag as a matter of course.

Viewing from the benefits of airbags by region of the body in five configurations where the airbags deployed, there was benefit of 3 in the change in AIS in legs, in the two configurations of 114-25/50 and 225-0/50. Viewing from the point of risk by each of body region, there was a risk of 1 in the change of AIS in the head in the two configurations of 414-25/50 and 114-25/50. Those were due to the injury indices measured when the dummy contacted to the ground. Viewing the change in NIC of all integrated body locations in the five configurations where the airbags deployed, two configurations had benefits of 0.11 and 0.16, while two other configurations had no influence, and one configuration had a risk of 0.07.

The changes in total average NIC of seven impact configurations are shown in Table 6, taking into account the occurrence frequency of impact configuration as shown in the accident database of ISO/CD 13232. The total average benefit is 0.03, and the total average risk is zero.

It is judged, therefore, that the airbag has no risk from the assessment of full scale impact tests based on ISO/CD 13232.

EVALUATION OF RIDER INJURY REDUCTION PERFORMANCE BY COMPUTER SIMULATION

Method of Computer Simulation

Rider injury reduction performance was evaluated by computer simulation based on ISO/CD 13232. However, the evaluation area specified by ISO/CD 13232 is limited to the area up to 0.5 seconds after the dummy hits the opposing vehicle (hereinafter referred to as primary impact sequence). In the computer simulation used for this research, evaluation was made until the time of dummy/ground contact (hereinafter referred to as secondary impact sequence) after the primary impact sequence. Honda obtained the computer simulation technology used in the assessment to enable the simulation of the level of injury until the time dummy/ground contact. (Refer to the SETC thesis). The explicit FEM software of FEM mode base (LS-DYNA) was used as the software for this simulation.

Based on the results of measurement of deformation characteristics of opposing vehicles in impact and those of full scale impact tests, the computer simulation method used in the assessment was prepared. And, based on the results of full scale impact tests in accordance with ISO/CD 13232, the extent of coordination of the measured indices of injuries in the computer simulation was validated. As the results of validation, comparison of the results of full scale impact tests on major injury indices and those of computer simulation are shown in Fig.10 to Fig.12. The HIC in the primary impact sequence is shown in Fig.10 while the HIC in the secondary impact sequence is shown in Fig.11. The maximum compression rate on the chest in the primary impact sequence is shown in Fig.12. Shown in Table 7 is the occurrence of the fracture of femur, knee, tibia in the domain combining the primary and secondary impact sequence (hereinafter referred to as entire impact sequence). From the results of validation of the

Table 5.
Airbag injury benefits and risks, by impact configuration and body region

Collision configuration	AIS change					NIC change
	Head	Neck	Chest	Abdomen	Leg	
413 - 0/50	0	0	0	0	0	0
413 - 25/50	0	0	0	0	0	0
414 - 25/50	-1	0	0	0	0	-0.07
412 - 25/50	--	--	--	--	--	--
114 - 25/50	-1	0	0	0	3	0.11
225 - 0/50	0	0	0	0	3	0.16
143 - 35/0	--	--	--	--	--	--

Table 6.
Average benefits and risks, all tests

Total average benefit	0.03
Total average risk	0
Ratio of risk / benefit	0

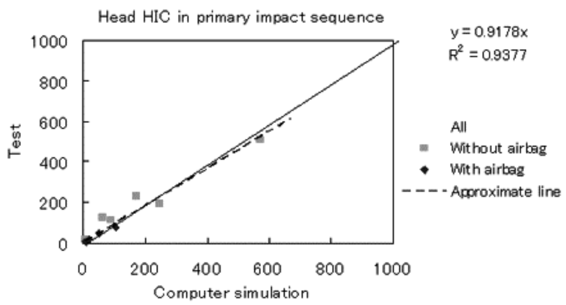


Figure 10. Correlation of head HIC for primary impact sequence.

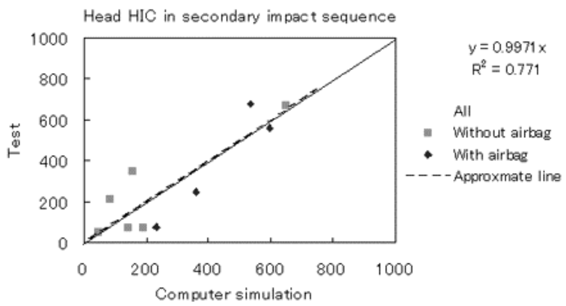


Figure 11. Correlation of head HIC for secondary impact sequence.

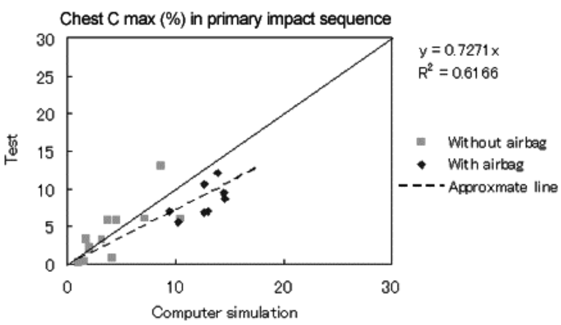


Figure 12 Correlation of chest compression (Cmax %), for primary impact sequence.

Table 7.
Correlation of leg fracture for entire impact sequence

Fumurs

		Full scall tests: Fracture	Full scall tests: No fracture	Present collect
Simulations	Fracture	0	1	96%
	No fracture	0	23	

Knees

		Full scall tests: Fracture	Full scall tests: No fracture	Present collect
Simulations	Fracture	0	0	100%
	No fracture	0	24	

Tibias

		Full scall tests: Fracture	Full scall tests: No fracture	Present collect
Simulations	Fracture	1	0	100%
	No fracture	0	23	

extent of this coordination, the computer simulation was judged to be capable of assessing the risk - benefit of injuries on 200 configurations specified in ISO/CD 13232.

Results of Computer Simulation

By using the computer simulation technology described above the evaluation of benefits and risks was conducted on 400 cases in 200 configurations based on ISO/CD 13232.Computer simulation was not conducted for the 79 impact configurations that the airbag was not expected to deploy because of no influences to rider injury. We conducted 242 cases in 121 configurations and with and without an airbag.

Figure 13 shows the results.Total average benefit is 0.048, risk is 0.004. Benefit/Risk ratio is 0.083, and average net benefit is 0.044. From these results, it can be said that this airbag system has an appropriate performance of rider injury reduction.

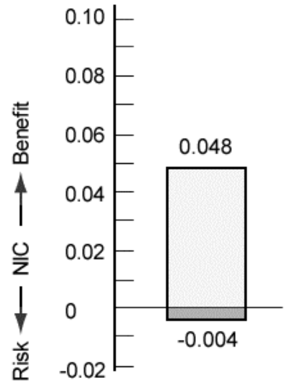


Figure 13. Total average benefits and risks, 200 impact configurations.

TESTS UNDER VARIOUS CONDITIONS AND THEIR RESULTS

The purpose of impact tests in seven configurations of ISO 13232 is to assess the risk and benefit in typical collisions. In addition to these evaluation based on ISO/CD 13232, to clarify the effectiveness of airbags in reducing injuries while minimizing the potential injuries caused by airbags, other tests were conducted by employing other configurations of impact and other rider conditions.

Influence of Rider's Size

In order to validate the differences in the absorbing performance of the rider's kinetic energy by the airbag and the differences in the presence of injuries in interference with the airbag when the size of riders changes, sled tests were carried out using three sizes of dummy. A dummy of standard size, AM50%ile (H-III), one representing smaller size, AF05%ile (H-III), and a dummy representative of large size, AM95%ile (H-III), were used. The measurement and assessment of injury indices were made in accordance with the stipulations and information of FMVSS 208[8][9] with respect to the head, neck and chest. As to the AM50%ile dummy neck, we replaced it with the MATD neck for measurement and evaluation based on ISO/CD 13232.

The acceleration waveform of sled in the tests was based on the deceleration waveform caused on a motorcycle when the motorcycle collides against a stationary opposing vehicle at a speed of 50km/h. The acceleration waveform is shown in Fig.14. The conditions of motorcycle and dummy set on the sled are shown in Fig.15.

The change in the upper half of the dummy body in the test results is shown in Fig.16. The figure shows that if the speed change was 50 km/h the energy is absorbed 100%, whereas if it exceeds 50 km/h the dummy rebounds from the airbag and if it is below 50 km/h the energy is not fully absorbed. As compared with the AM50, the standard dummy, the absorbing performance of the airbag is reduced for the larger AM95, and is enhanced in the smaller AF05. None of these three dummies separated toward the front of motorcycle. Figure 17 shows the condition in which the absorption of the kinetic energy of the dummy ceases. The results of measurement of injuries on dummies are shown in Table 8. There was no injury index that exceeded the criteria for the head, neck and chest in any of the three dummies used.

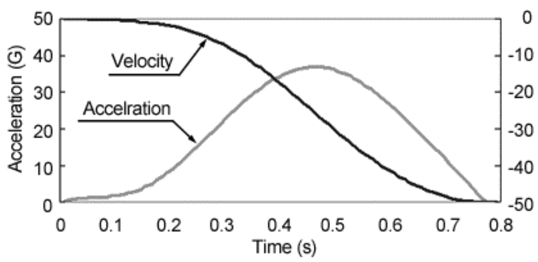


Figure 14. Acceleration and velocity change of motorcycle, in sled tests.

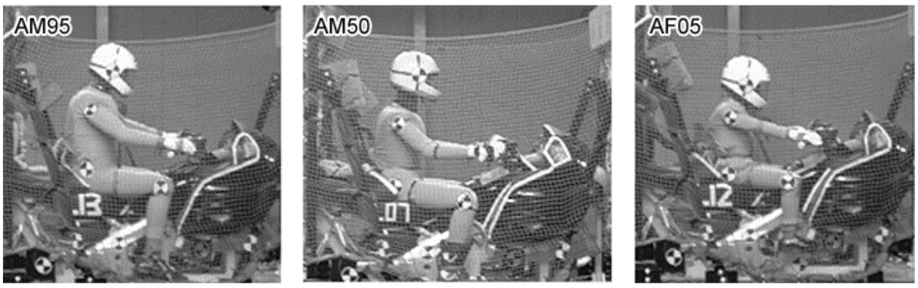


Figure 15. Initial dummy posture in sled test.

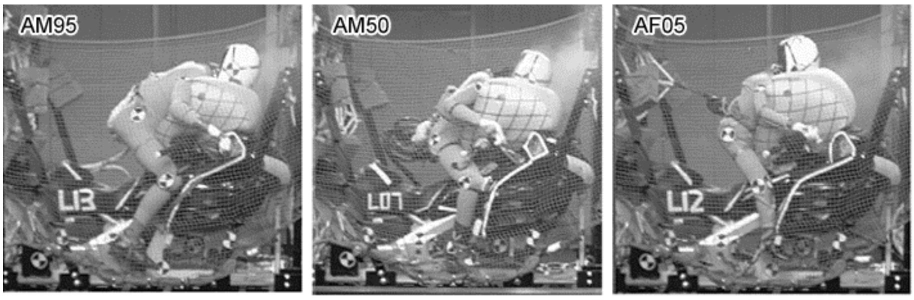


Figure 17. Dummy posture at the moment when kinetic energy absorbed with airbag.

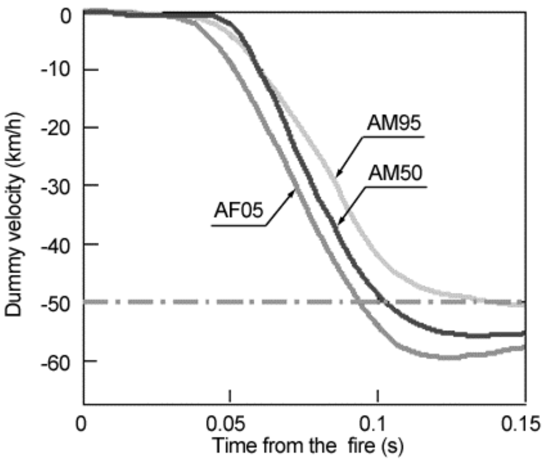


Figure 16. Velocity change of dummy's upper body.

Table 8.
Dummy injury indecis in sled test results

Dummy size	Head HIC	Neck Nij (or NII)	Chest D max.
AM95	52 (not over 700)	0.56 (not over 1)	32 (not over 70mm)
AM50	134 (not over 700)	2.0 * (not over 4)	26 (not over 63mm)
AF05	134 (not over 700)	0.73 (not over 1)	17 (not over 52mm)

* Neck NII is defined by ISO/CD 13232, NII 4 is approximately AIS 2. Other injury assessment are defined or informed by FMVSS 208.

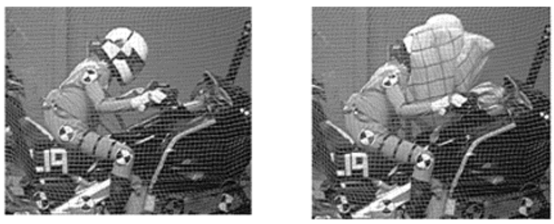
Influence of Airbag Deployment in Tilted Forward Posture of Riders

One needs to consider that motorcycle riders change their posture during riding. In particular, the rider should not be seriously injured by the deploying airbag even if the airbag deploys while the rider takes a posture tilted forward into the area of airbag deployment. A static deployment test validated that no injury will be inflicted by the deployment of the airbag. It was assumed in the validation tests that the rider dummy would take "a marginal forward tilt to enable them to secure a sufficient visibility in the front". Dummies representing standard size, AM50%ile (H-III), and AF5%ile (H-III), representative of smaller size, were used. The measurement and assessment of injuries were made in accordance with the stipulations of FMVSS208 with respect to the head, neck and chest. As to the AM50%ile dummy neck, we replaced it with the MATD neck for measurement and evaluation based on ISO/CD 13232.

The conditions of the dummies before and during the deployment of airbags in shown, the case of AM50 is shown in Fig.18 and that of AF05 in Fig.19, respectively. In either of cases, the airbags deployed first in the vicinity of chest and neck and then interfered with the head and bent the neck of the dummy backward. The results of indices of injuries on the dummies are shown in Table 9. For both AF05 and AM50 no recorded injury index exceeded the criteria.

AM50 Before deployment AM50 During deployment

Figure 18. Static inflation test with forward leaning AM50-dummy.



AF05 Before deployment AF05 During deployment

Figure 19. Static inflation test with forward leaning AF05-dummy.

Table 9.
Measured dummy injury in static inflation test with forward leaning dummy

Dummy size	Head HIC	Neck Nij (or NII)	Chest D max.
AM50	168 (not over 700)	1.55 (not over 4)	5.5 (not over 63mm)
AF05	37 (not over 700)	0.53 (not over 1)	0.4 (not over 52mm)

* Neck NII is defind by ISO/CD 13232, NII 4 is approximatery AIS 2.
Other injury assessment are defined or informed by FMVSS 208.

Influence of High-speed Impact and Influence of Passenger

To judge the feasibility and effectiveness of the airbag system, it is necessary to validate whether the airbag will retain the rider kinetic energy absorbing performance, including its strength, under more severe impact conditions. To present more severe impact conditions for this analysis, the combined conditions of two-up riding and higher impact speed were set. The addition of the condition of two-up riding was used to analyze the potential compression of rider's chest influenced by the phenomenon that the passenger will push from the back while the rider is held by the airbag in the front.

The impact test was set as follows: To a stationary motorcycle equipped with the airbag the opposing vehicle, a Honda Accord, will collide at a speed of 75 km/h. Having the opposing vehicle collide with a stationary motorcycle is used to suppress the pitching of motorcycle body, and therefore is considered more appropriate for the purpose of the test. The impact speed was set at 75 km/h in an attempt to be inclusive of most of accident speeds, referring to accident data of ISO/CD 13232 as shown in Fig.20. For the rider dummy, the MATD was used and indices of injuries were measured and assessed in accordance with ISO/CD 13232. For the passenger dummy, AM95%ile (H-III) was used, as it would have the greatest impact to the rider dummy and airbag. Since the assessment of injury using an AM95 dummy would require wired electrical measurement, which should be avoided in full scale impact tests of motorcycles, no assessment was made of indices of injuries to the passenger dummy.

During the impact test, the rider dummy was caught between the airbag and passenger dummy as shown in Fig.21. Afterward the passenger dummy separated to the front of the motorcycle, but the rider dummy stayed on the motorcycle which absorbed its kinetic energy. In the test, no breakage was caused to the airbag. The measured injuries indecis on the rider dummy during primary impact sequence are shown in Table 10. In the index of injury to the upper half of the dummy body, injury which should be directly attributable to the airbag, no injury index countable by AIS was caused on the head, neck and abdomen except AIS 1 in the chest.

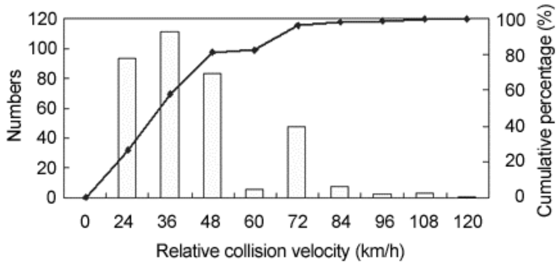


Figure 20. Frontal collision speed based on ISO 13232 accident data.

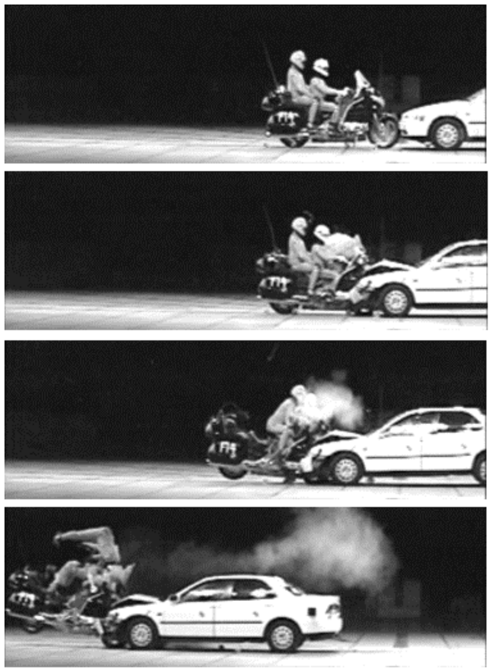


Figure 21. 75km/h impact test with passenger.

Table 10.
Measured injury of rider dummy in 75km/h full scall impact test

Rider dummy	Injury by body region (AIS)			
	Head	Neck	Chest	Abdomen
MATD	0	0	1	0

Front Wheel Non-impact Collision (Under-ride Impact)

In a variety of frontal collision accidents, there is a configuration in which the front wheel of the motorcycle will not be the first point of contact with the opposing vehicle or object, such as in the collision of a motorcycle to the platform of a truck (hereinafter referred to as Under ride impact). Under ride impact tests were conducted to validate whether rider injury reduction would be possible in the present airbag system wherein the timing of deployment decision and the airbag deployment decision are based on the deceleration of the front wheel system.

To an impact trolley, as shown in Fig.22, to which brake is applied, a motorcycle mounted with an airbag was collided at a speed of 50 km/h. To the opposing trolley, a colliding plane was attached simulating the platform of a truck. The principal dimensions of the impact trolley are shown in Table 11. The MATD was used for the rider dummy, and measurement and assessment of injury index was made in accordance with ISO/CD 13232.

As the results of the under ride impact test, the timing of collision judgment by the sensing system was 30msec. after initial impact. The dummy did not directly hit the opposing impact plane, rather the dummy made contact with the airbag in the process of deployment, and the airbag absorbed the kinetic energy of the dummy. Figure 23 shows the conditions of the airbag and dummy. The results of evaluated injury index are shown in Table 12. No airbag related countable injury index took place on the head, neck, chest and abdomen in terms of AIS.

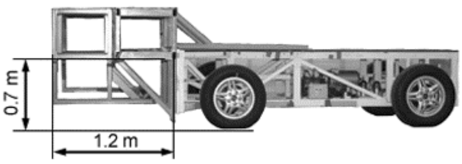


Figure 22. Opposing trolley used under-ride impact test.

Table 11.
Opposing trolley specificastions

Mass	1750 kg
Overall length	4250 mm
Overall width	2080 mm
Overall height	1300 mm

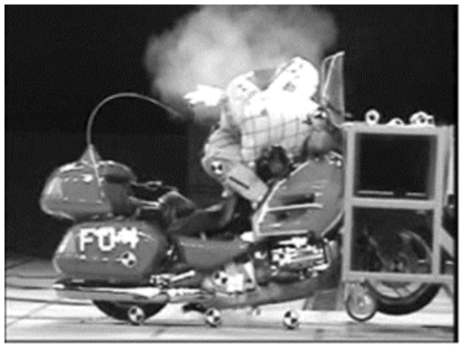


Figure 23. Under ride impact test.

Table 12.
Measured injury in under ride impact test

Rider dummy	Injury by body region (AIS)			
	Head	Neck	Chest	Abdomen
MATD	0	0	0	0

EXAMINATION OF RIDER INJURY REDUCTION EFFECTS OF THE AIRBAG

Using the evaluation to assess the risk potential of airbags based on ISO/CD 13232 and from the results of other validation, a judgment was made regarding the use of airbags. As regards the benefit of the effect of reducing injury it appears that a clear conclusion can not yet be made. Namely, in the impact test on 50 km/h level as specified in ISO/CD 13232, no severe injury index has occurred on the base motorcycle without the airbag. From the measured index of direct injury on the dummy, therefore, the effects of injury prevention and reduction by the airbag are not visible. Accordingly, the rider injury reduction effects expected of the airbag will be examined by analyzing the fatal accident data in the base motorcycle used for the airbag tests and test results this time.

Analysis of Accident Data in Base Motorcycle Used for Airbag test

The conditions of the occurrence of injuries in actual accidents involving the base motorcycle used for the airbag test appear different from the case of other motorcycles because of the characteristic of being a large and heavy motorcycle. The accident data were analyzed from this point of view. Figure 24 shows the result of an analysis of the relationship between the collision speed in frontal collision and the number of fatalities in motorcycle riders. "All motorcycles" are based on the fatal accident data of motorcycles except those with displacement less than 50cc in the years from 2000 to 2002 in Japan [10] "GL" is based on the fatal accident data of Honda GL1000, GL1100, GL1200 and GL1500 from 1975 to 2003 in the U.S.A.[11]. As the result of filtering to cases with required information, "All motorcycles" represent the data of N=700 while "GL" N=234. The base motorcycle used in this study was applied to and interpreted as forming a part of "GL". Collision speed data in the chart were obtained as follows: The original data did not show the actual collision speed, but rather the perceived speed at which the rider felt the collision was unavoidable(hereinafter referred to as precipitating speed）. Both motorcycle and opposing vehicle collision speed were calculated by multiplying the precipitating speed by 0.7. The number 0.7 is set based on the report of motorcycle accident analysis issued by USC [12] . The collision speed here is assumed to be the combined speed of motorcycle and opposing vehicle; in case of collision against the front of opposing vehicles the sum total of both speeds; in case of collision to the side of opposing vehicles the speed of motorcycle; and, in case of collision to the rear of opposing vehicles the speed of opposing vehicle was deducted from that of the motorcycle.

According to the results of an analysis of the accident data, the fatal accidents covered at 50km/h level accounted for approximately 70% of "All motorcycles" and about 30% of "GL". It can be seen that as compared with "All motorcycles", "GL" is less likely to sustain fatal injury on the same collision speed. Because of this characteristic of "GL", no severe injury index was measured in the impact test at 50 km/h of the base motorcycle.

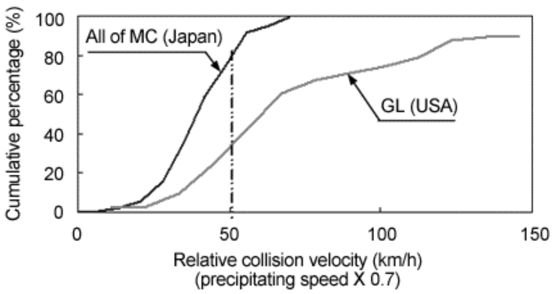


Figure 24. Fatal accident data of motorcycle.

Analysis of Effectiveness of Airbags Seen from Impact Velocity of Rider Dummy to Opposing Vehicle

With respect to the results of full scale impact tests as specified in ISO/CD 13232, an examination was made on the effects of preventing impact by the motorcycle rider to the opposing vehicle or reducing the rider’s impact velocity through the suppression of the forward separation of the rider, which was the aim of the airbags. In both impact configurations of 413-0/50 and 413-25/50, head injury to the dummy on the base motorcycle without airbags was prevented. In the base motorcycle without airbag, the HIC of the dummy head which hit the opposing vehicle was 115.1 in the case of 413-0/50 and 122.3 in the case of 413-25/50 as shown in Fig.25. Figure 25 shows for reference the HIC that occurred in the airbag-equipped motorcycle. Though the HIC of the base motorcycle is larger than that of the airbag-equipped motorcycle, it is still low and under AIS 1.

The result of an analysis of dummy motions, disclosed that the absolute head velocity of the dummy at the time of impact to the opposing vehicle on the base motorcycle without airbag was 8.0m/s in case of 413-0/50 and 10.0 m/s in case of 413-25/50 as shown in Fig.26. The results of helmet tests conducted in connection with the study are shown here in Fig.27 In accordance with the helmet test method of JIS (JIS T8133-2000) [13], an impact test was carried out wherein a plane anvil was impacted with the top of the helmet used in the full scale impact tests. According to the results of this helmet test, HIC 2500 is exceeded at impact velocity of approximately 7 m/s when hit against the plane of the rigid body. Therefore, at the impact velocity of 8.0m/s in the case of 413/0/50 and at 10.0 m/s in case of 413-25/50, there exists a possibility of causing serious injury to the head depending on the shape and hardness of colliding object. This could happen in actual accidents wherein various opposing collision vehicles and other objects of collision exist, and they constitute part of fatal accidents in the low-speed collision of the accident data formerly described. In the airbag-equipped motorcycles, the impact to the head which occurred in the base motorcycle could be prevented or reduced.

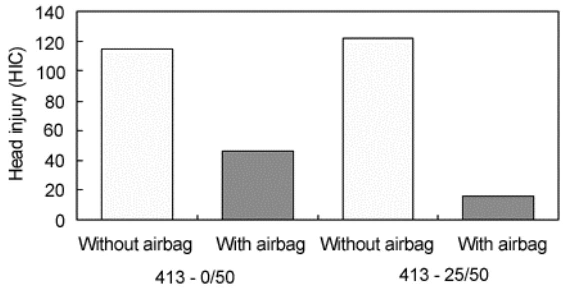


Figure 25. Head HIC in 413-0/50 and 413-25/50.

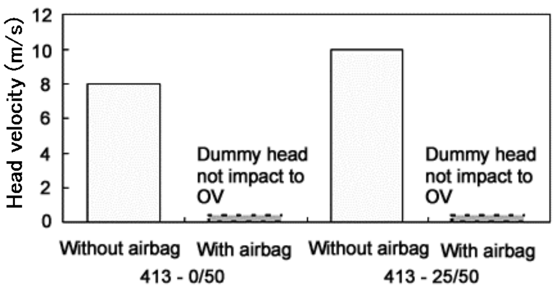


Figure 26. Head velocity of impact to opposing vehicle.

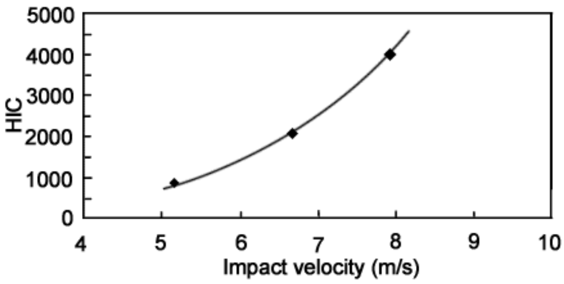


Figure 27. Helmet impact test result.

Effect of Rider Injury Reduction Expected in More Collision Conditions

From the results of analysis of fatal accident data described above, rider injury reduction is desired in much higher collision speed ranges. The airbag absorbed the kinetic energy of rider dummy in the impact test at a speed of 75 km/h and prevented the rider dummy from forward separation from motorcycle without causing injury through the interference with the airbag. Therefore, the effect of reducing fatal injury can be expected in collisions at a speed on the 75 km/h level of "GL", as seen in the accident data described above.

The effects in impact in high-speed ranges were validated in some of the impact configurations in the assessment by computer simulation described above. For instance, in the impact configuration of 414-0/72 shown in Fig.28, injury indices as shown in Table 13 were calculated. In the impact configuration, the rider's head impact to the opposing vehicle, which occurred to the base vehicle, is prevented by the airbag and the injury of the rider is substantially reduced.

In the results of assessment of indices of injuries on the dummy in a series of full scale impact tests of ISO/CD 13232, the rider injury reduction effects of the airbag did not show clearly. However, from this examination, an expectation is held that the airbag system will considerably contribute to the reduction of fatal injury and serious injuries of riders.

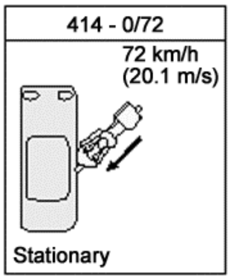


Figure 28. Benefit impact configration from computer simulation

Table 13.
Injury change, 414-0/72

Collision configulation	AIS change					NIC change
	Head	Neck	Chest	Abdomen	Leg	(Whole body)
414 - 0/72	4	0	0	0	3	0.80

＊ Positive number means benefit, negative number means risk

CONCLUSION

GL1800 equipped with prototype airbag system was evaluated by full scale impact tests based on ISO/CD 13232, computer simulation and other tests set up by Honda.

As the result, the following findings were obtained:

- The sensor system, making judgment by detecting and calculating the deceleration of the front wheel system, was capable of properly judging deploy/no-deploy against the situations of collision/non-collision.
- As the result of full scale impact tests in accordance with ISO/CD 13232, the total average risk was zero in seven configurations.
- As the results of computer simulation analyzing the time until dummy/ground contact with and without airbags in 200 configurations, the total average benefit was 0.048, risk was 0.004. It can be said that the performance of rider injury reduction system is appropriate.
- As the result of validating impacts under a variety of conditions which should be taken into account, including two-up riding impact, 75 km/h impact, different sizes of rider, rider posture tilted forward ,as well as the under ride impact, no unacceptable phenomena have occurred.
- As the result of studying the effectiveness, based on the accident data, of the base motorcycle and the test results of the airbag, it was possible to conclude that the airbag system is effective in reducing fatal and serious injuries to riders.

It is judged from the foregoing that the airbags for large touring motorcycles would have the possibility of becoming a reality. Development will be made in future aiming at putting the airbags to practical use in consideration of durability, weather ability, reliability, commodity value and productivity.

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ADVANCED MOTORCYCLE HELMETS

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Paper 05-0329

ABSTRACT

More than 5,000 motorcycle riders or pillion passengers are killed annually on European roads and a further 70,000 are seriously injured. In addition to the physical and emotional trauma, the financial cost of these injuries is estimated to exceed 10 billion Euros. The COST 327 European Research Action on motorcycle helmets reported that improvements in helmet design could save up to 1,000 lives per year across the European Union. Approximately 80% of motorcyclists killed on European roads sustained head impacts and in half of these cases, the head injury was the most serious.

TRL has developed with industry an advanced protective helmet which provides a higher level of protection than current helmets to BS 6658A, ECE Regulation 22-05 or Snell M2000. The helmet consists of a lightweight carbon composite shell fitted with an optimised energy absorbing liner and a low friction sacrificial outer surface. The advanced helmet is designed to reduce both linear and rotational acceleration loadings to the head.

In order to quantify the benefits of the advanced helmet, the impact response was measured during a range of impact conditions. The results were related to the AIS scale using correlation coefficients developed by TRL from an accident replication programme. It was shown that the advanced helmet could reduce injury risk by up to 20% for AIS 6 injuries and up to 70% for AIS 5 and AIS 4 injuries. The performance of the helmet during less severe impacts (corresponding to AIS 3, 2 and 1) was designed to be equivalent to current helmet designs.

Given this potential, the UK Department for Transport is collaborating with domestic and European partners in a new project to encourage the introduction of more protective motorcycle helmets. This paper describes the work to date and prospects for the future.

INTRODUCTION

Research conducted by the COST 327 European Research Action [1] on motorcycle helmets concluded that head injury severity increased, quite remarkably, with head impact speed. More than 5,000 motorcycle riders or pillion passengers are killed annually on European roads and a further 70,000 are seriously injured. It was postulated that if helmets could be made to absorb 24% more energy then some 20% of the AIS 5-6 casualties would sustain reduced injuries of only AIS 2-4. Furthermore, an increase in helmet energy absorbing characteristics of some 30% would reduce 50% of the AIS 5/6 casualties to AIS 2-4.

Research was carried out in parallel by TRL and industry to develop a prototype of an advanced helmet design capable of satisfying both the safety performance specified by COST 327 and geometric, mass and ergonomic requirements based on current motorcycle helmets designed to BS 6658A [2] or ECE Regulation 22-05 [3].

There were two principal objectives for the new helmet (A) ultra stiff shell structure and optimised liner (B) low friction outer surface.

A) The aim of the ultra stiff shell structure was to ensure that the outcome of a linear impact (or component thereof) was independent of the profile of the impacted surface. Thus the protection provided by the helmet corresponded to the characteristics of the liner material and thickness. The liner could then be optimised for internally induced deformation caused by the head moving into the liner. By this approach, externally induced deformation that arises, for example, by the shell of a current helmet deforming when striking a kerbstone anvil, was reduced to a negligible amount.

B) The aim of the low friction surface was to reduce tangential impact loads during oblique impact conditions, thus minimising the rotational accelerations imparted to the head, whilst correspondingly reducing the resultant force and, therefore, reducing the resultant linear acceleration.

This paper describes the development programme for the new helmet and demonstrates how the COST 327 objectives were exceeded. An injury benefit analysis was conducted based on the safety performance of the new helmet. The analysis considered the distribution of injury mechanisms and severities for the riders injured on roads in Great Britain and determined the extent to which the distribution may be improved if advanced helmets had been worn. It was concluded that up to 20% of fatal rider injuries in Great Britain could be prevented. If the same proportion of injury reduction could be achieved on European roads more than 1,000 lives per year could be saved.

The advanced prototype helmets were produced using relatively expensive materials and processes. It was, therefore, important to consider the cost of such helmets if mass produced to achieve significant sales penetration. The dominant cost issues are discussed within this paper, together with new work which, it is hoped, will reduce these further to allow for greater penetration.

HEAD INJURY MECHANISMS

A helmet is designed to protect the rider in the event of an accident by absorbing impact energy and reducing the loading imparted to the head via the helmet. In order to maximise the protection provided by a helmet, it is important to identify the mechanisms by which a head becomes injured. The term ‘head injury’ comprises various kinds of trauma to the skull and its contents. Usually, several different types of head injury occur simultaneously in a traffic accident. The anatomical location of the lesions and their severity determine the physiological consequences. Injuries may be divided into cranial injuries (skull fractures) and intracranial “soft tissue” injuries. Indeed, skull fracture can occur with or without soft tissue damage and vice versa.

Skull fracture occurs when the loading on the skull exceeds the strength of the bone and can be either open or closed. Skull fractures may be divided into facial, vault and basal. The most threatening form of skull fracture is basilar skull fracture. A characteristic of motorcycle accident victims is that fractures of the vault are rare among helmeted riders, but that basilar skull fractures are frequently encountered, both in helmeted and unhelmeted riders [4 and 5]. Soft tissue damage occurs, during an impact, due to high strains within the vascular and neurological tissues as a result of both linear and rotational loadings to the head.

The risk of both types of injury (skull fracture and soft tissue) can be reduced by improving the energy absorbing performance of the helmet. The advanced TRL protective helmet achieves this with a liner-shell combination of appropriate stiffness to minimise linear acceleration during high energy impacts. In addition, the outer surface of the helmet provides very low friction, so that the rotational accelerations imparted to the head are minimised.

SPECIFICATION FOR MOTORCYCLE HELMET SHELL – LINEAR IMPACT

The objective of the new helmet was to exceed the safety performance objectives of the COST 327 European Research Action on motorcycle helmets. A target improvement in linear impact energy absorption of 75% was proposed; corresponding to impact tests at 10m/s compared with 7.5m/s for ECE Regulation 22-05.

This could be achieved, in part, by optimising the performance of the shell to be very stiff and able to resist excessive shell deformations and thus transmit loads more efficiently to the energy absorbing liner. It was proposed that the mass of the shell should not be greater than that of current designs and should be reduced, if possible. It was accepted that the thickness may need to be increased, compared with current designs (which are typically 3mm), in order to achieve the objectives. A maximum thickness of 10mm was proposed. The materials were specified such that a helmet shaped structure with double curvature could be achieved and volume production would be practicable. In addition, it would be beneficial for the structure to possess inherent damping qualities that would minimise rebound during impacts.

To meet these objectives, flat coupons tests (see below) were used to develop helmet shell materials and further full geometry tests to identify optimal liner materials. Further prototype helmet tests were completed to evaluate the performance benefits of the advanced helmet over current helmet designs.

PERFORMANCE ASSESSMENT USING FLAT COUPONS

The impact characteristics of the shell were assessed together with consideration of temperature and moisture stability, mass, thickness and scope for production. Durability was not considered at this stage. TRL developed specific test procedures to enable the evaluation of shell structures using flat samples of shell material. The cost of manufacturing and testing flat shell samples was very much lower than for helmet shaped shell structures, therefore a greater number of potential designs could be evaluated. The dynamic loads exerted during the flat sample tests were representative of those exerted during complete helmet test, therefore it was possible to evaluate the flat shell structures for use in complete helmets.

It was important that the results from the tests on flat samples represented the performance of complete helmets, constructed with the same materials. In order to ensure this, the test procedures were representative of a falling headform test. The acceleration-history of the impactor during these flat coupon tests was related to the acceleration-history of a helmeted headform during similar impact conditions.

Linear impact tests - Flat shell samples measuring 120mm x 70mm were attached to a ‘bed’ of energy absorbing foam measuring 120mm x 70mm x 35mm using double sided adhesive tape. The foam used had energy absorbing properties similar to the Expanded Polystyrene (EPS) used in motorcycle helmets. The foam/shell specimen was attached to the base of a 2.5kg mass, with the shell facing outwards. The specimen was impacted onto a steel hemi-spherical anvil with a 25mm radius. The anvil was designed to simulate the shell-stresses developed during a helmet impact onto the ECE Regulation 22 kerbstone anvil. The impactor was fitted with a single axis accelerometer and the signal was recorded in accordance with SAE J211 (CFC1000). Tests were conducted at 5m/s, 7.5m/s and 10m/s.

Temperature and moisture tests - The samples were pre-conditioned for a minimum of 4 hours at -20°C, +25°C, +50°C and with moisture conditioning by means of submersion in a water bath. The samples were placed on a rigid anvil, with the shell facing upwards, and impacted with a 2.5kg mass fitted with the steel hemi-spherical impact surface as above. The impactor was fitted with a single axis accelerometer and the signal was recorded in accordance with SAE J211 (CFC1000). Tests were conducted at 7.5m/s.

Analysis and results - For each test the acceleration history of the impactor was recorded. By single integration of this result the velocity history was calculated and hence the rebound velocity was determined. By double integration of the acceleration result, the displacement history was calculated and this enabled the maximum dynamic displacement to be determined.

A specification was defined for the flat coupons to achieve the proposed helmet shell performance. This was considerably more advanced than that of current helmet designs, and was thought to be close to the limit of what was technically achievable. The requirements were closely met and allowed the helmet performance to be optimised within the constraints of a current helmet mass. A summary of this specification is given in the Table 1 below;

Table 1 - Performance target for flat coupons

Size	120mm * 70mm
Thickness	Maximum of 10mm
Mass	Maximum of 50g
In-plane tensile strength	Peak tensile stress will occur at the *inner surface* and will be dependant on the thickness of the structure. In the region of 250N/mm² for a 5mm thick structure or 60N/mm² for a 10mm thick structure.
In-plane compressive strength	Peak compressive stress will occur at the *outer surface* and will be dependant on the thickness of the structure. In the region of 250N/mm² for a 5mm thick structure or 60N/mm² for a 10mm thick structure.
In-plane bending stiffness	10 times as stiff as 3mm GRP (or 5mm unreinforced polycarbonate).
Through-thickness compressive strength	Management of compressive forces without excessive dimpling to the outer skins. Peak compressive stresses approximately 30N/mm² at 1.5mm shell deformation.
Operating conditions	-20°C to +50°C with extremes of moisture

FLAT COUPON LINEAR IMPACT TESTS

The structural requirement for the shell structure was to transmit the impact force between the impact surface and the energy absorbing liner material, without excessive deflection or structural failure. In order to achieve this, the structure must also resist the high local contact stresses at the point of impact, without excessive local deformation.

To define acceptable levels of shell deformation, TRL investigated the impact performance of an infinitely stiff shell structure which does not deflect during impact. This was achieved by impacting samples of the energy-absorbing foam between parallel plates in accordance with the procedures used for shell evaluation discussed above. In order to transmit the impact forces to the energy absorbing liner, the maximum acceptable shell deformation was estimated to be 3mm during a 7.5m/s impact and approximately 5mm during a 10m/s impact.

The linear impact performance of the coupon structures were further analysed using the acceleration-time history and acceleration-displacement of the impactor. At 7.5m/s the peak deformation of the impactor was 18mm and at 10m/s the peak deformation of the impactor was 27mm. These results were combined with the target values for shell deformation to prescribe target displacement values of 21mm at 7.5m/s (18mm+3mm) and 32mm at 10m/s (27mm + 5mm).

In addition to impactor displacement, it was possible to evaluate the results in terms of impactor acceleration and define appropriate limits for these performance parameters. At 7.5m/s, the infinitely stiff shell achieved a peak acceleration of 200g and when tested at 10m/s the peak acceleration was 300g. The acceleration results from tests on less stiff shells were, implicitly, lower than those for the infinitely stiff shell *(except when the shell was so soft that the impactor bottomed out, hence producing a very high acceleration result)*. It was therefore proposed that the novel shell structures should achieve acceleration levels slightly lower than for the infinitely stiff shell tests. Based on this concept, the prescribed target values for peak impactor acceleration were;

i. at least 180g during impact at 7.5m/s
ii. no more than 300g during impact at 10m/s

Although a high stiffness is a fundamental requirement of the 'novel shell design', it may be an advantage for the shell to deform or yield during severe impact conditions, so that the space occupied by the thickness of the shell may be fully utilised. This characteristic was also investigated during the evaluation of the 'novel structures'.

Test samples for linear impact tests

The following test samples were evaluated;

1 Polycarbonate - 5mm thick
2 Polycarbonate - 10mm thick
3 Nimrod helmet shell sample - 5mm thick
4 Aluminium plate - 5mm thick
5 Carbon-sandwich (CS-01) - 4.1mm
6 Carbon-solid (CS-02) - 2.9mm
7 Carbon-experimental (CS-08) - 3.0mm

Results for linear impact tests

A summary of the tests data is provided in Table 2. The design values are also included.

The baseline polycarbonate and aluminium materials did not achieve the target performance values. These materials were found to have an insufficient strength to weight ratio such that when the mass criterion was met, the impact performance was not achieved, and when the thickness (and therefore strength) was increased to meet the impact performance, the mass became prohibitively high.

Three different variations of composite design were used. All three were constructed using carbon fibre composite materials. CS-01 was a sandwich construction with a syntactic foam core, CS-02 was a solid laminate and CS-08 was an experimental laminate. Both CS-01 and CS-02 achieved all the target values for mass, thickness, deformation and acceleration. CS-08 met all but the deformation target during the 10m/s test, with a deformation of 34mm compared with the target of 32mm. It was found that the performance of all the carbon structures was stable after the temperature and water conditioning.

Table 2. Summary of test results from Carbon composite coupon structures

Sample	Mass [g]	Thickness [mm]	Peak Deformation [mm]		Peak Acceleration [g]	
			7.5 m/s	10 m/s	7.5 m/s	10 m/s
Rigid flat plate			18	27	202	300
Target	***≤50***	***≤10***	***≤21***	***≤32***	***≥180***	***≤300***
PC (5.0mm)	50	5	**23**	**35**	**157**	**364**
PC (10mm)	**100**	10	18	28	195	288
Nimrod (5.0mm)	45	4.5	**25**		**144**	
Al (5.0mm)	**117**	5	18	26	204	293
CS - 01 (4.1mm)	40.6	4.8	21	30	200	298
CS – 02 (2.9mm)	36.2	3.0	20	32	210	242
CS - 08 (3.0mm)	39.7	3.0	21	**34**	193	293

Results in **bold** did **not** achieve target values

In summary, CS-01 and CS-02 achieved all the design targets and provided significantly improved performance compared to the baseline materials. These two materials were selected for testing with full-geometry helmet constructions.

SPECIFICATION FOR MOTORCYCLE HELMET SHELL – SURFACE FRICTION

COST 327 [1] reported that reducing the tangential force during an impact by 50% may reduce the injury outcome by one AIS category. It was, therefore, agreed that the new helmet should be developed with a shell system designed to minimise surface friction. A bespoke test method was devised to assess the potential solutions for the reduction of rotational motion by measuring the effective surface friction of flat coupon test samples. The tests samples included low friction coatings and a sacrificial layer designed to peel away with very little force.

The test configuration consisted of pseudo-dynamic surface abrasion tests using flat samples of shell material. Two test methods, using the same apparatus were utilised depending on the technique presented to reduce friction. Samples that presented a surface with a low coefficient of friction were evaluated using configuration ‘A’. Samples that presented a sliding-layer failure mechanism were evaluated using configuration ‘B’. The results from both methods were compared directly. TRL tested three variants with three tests per variant. Figure 1 shows the apparatus used.

The samples were located in a rigid housing and positioned against the flat horizontal track surface 300mm long and 150mm wide. A normal force was applied using a pneumatic actuator to clamp the sample against the track surface. The magnitude of this load was approximately 2,000N (to simulate the typical normal force during an oblique impact test to ECE Regulation 22-05 Method A). A tangential force was subsequently applied using a pneumatic actuator to slide the track surface relative to the test sample. The stroke of the tangential actuator was 100mm. The normal and tangential loads were measured with load-cells and the acceleration of the track surface carriage was measured with an accelerometer. The instrumentation data was recorded at a rate of 10,000 samples per second and filtered in accordance with SAE J211. A filter frequency of CFC180 was chosen after careful consideration.

For configuration (A): samples measuring 25mm x 25mm and between 2mm and 25mm thick, with a 2mm radius on one edge, were mounted in a rigid sample holder and clamped against a flat carriage fitted with 80 grit aluminium oxide paper. For configuration (B): samples measuring 120mm x 70mm and between 2mm and 25mm thick were mounted on a carriage and a 80 grit aluminium oxide tool measuring 25mm x 25mm was clamped against the surface of the sample.

Test samples for surface friction tests

For both configurations, the carriage was translated perpendicular to the clamping force over a minimum distance of 65mm and with a maximum speed of approximately 1.5m/s. By measuring the normal and tangential loads during the event, it was possible to calculate the effective dynamic coefficient of friction of the sample.

Three coupon samples were investigated as detailed below:

1 Polycarbonate (configuration A)
2 Carbon fibre composite with toughened epoxy matrix (configuration A)
3 Sacrificial layer (configuration B)

Test results for surface friction tests

A summary of the results are provided in Table 3 below. The baseline polycarbonate material achieved a peak friction of μ0.77 and a sliding friction of μ0.42. The carbon fibre material achieved significantly reduced friction values of μ0.17 peak and μ0.12 sliding, a reduction of almost 80% in peak friction. The sacrificial layer achieved the lowest values of μ0.10 peak and μ0.09 sliding, a reduction of almost 90% in peak friction. Both systems were further evaluated using full helmet shell tests.

Table 3. Summary of test results from flat coupon structures

Sample	Normal force [N]	Coefficient of friction (μ)	
		Peak	Sliding
Polycarbonate	1,900	0.77	0.42
Carbon fibre *(CS-01)*	2,000	0.17	0.12
Sacrificial layer	1,900	0.10	0.09

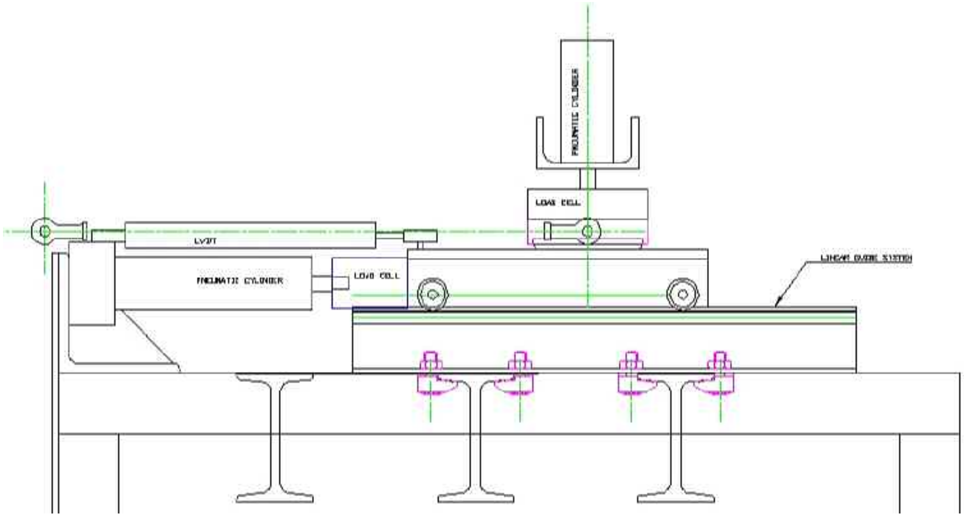

Figure 1. Low velocity, transient, surface friction test apparatus

FULL GEOMETRY HELMET SHELL TESTS

Tests were conducted on full-geometry prototype helmet samples in order to develop and evaluate the linear impact and oblique impact performance as defined by ECE Regulation 22-05.

LINEAR IMPACT DEVEOPMENT TESTS

The aim of the linear-impact development tests was to evaluate full-geometry prototype helmets with carbon shells to the laminate specification determined in flat coupon testing. The shells were fitted with Expanded Polystyrene (EPS) energy absorbing liners of different densities (25g/l and 30g/l) in order to determine the best compatibility between shell and liner. The prototype helmets were full-faced geometry construction, in size 57 (medium), and conformed to the extent of protection requirements of ECE Regulation 22-05. The impact area of the shell was profiled to closely fit the energy absorbing liner. The linear impact tests were conducted in accordance with ECE Regulation 22-05 using a rigid free-motion headform of mass 4.7kg. A total of five linear impact tests were conducted on each helmet design, with tests at 7.5m/s and 10m/s onto both the flat and kerbstone anvils with temperature conditioning at -20^{o}C, 25^{o}C and $+50^{o}$C.

Baseline tests were conducted on current full-faced GRP motorcycle helmets conforming to ECE Regulation 22-05. The results are shown in table 4 below. The baseline performance at 10m/s onto the kerbstone anvil (front) was 954g and onto the flat anvil (crown) was 299g. The carbon shell concept provided a significant improvement over the current motorcycle helmet design with a 10m/s kerbstone anvil (front) impact result of 235g (CS-02) and a 10m/s flat anvil (crown) result of 230g.

The results were analysed in detail to determine the best solution in terms of liner density and shell construction (solid laminate or sandwich), as described below.

Liner Density - During tests at 10m/s the 30g/l EPS liner achieved 235g on the front (CS-02) and 292g on the rear (CS-01) compared with 319g on the front and 890g on the rear for the 25g/l EPS liner. Based on these results, 30g/l EPS was considered to be the best solution for the main area of the energy absorbing liner. However, it was decided that the crown area should be of a lower density to compensate for the increased volume of liner that is compressed during a crown impact test due to the head geometry in this region. Evaluation of 25g/l EPS during crown impacts at 10m/s revealed a peak acceleration of 230g (CS-01) and 242g (CS-02). A 25/30g/l dual density EPS liner was therefore chosen as the best solution for the performance evaluation of the advanced helmet.

Shell construction - The results for the two carbon shell concepts were similar as can be seen by comparing the results for side impact onto the flat and kerb anvil: 185g and 173g respectively for the solid shell and 200g and 186g respectively for the sandwich shell. However, the solid shell had two advantages over the sandwich shell;

(1) reduced thickness, thus providing space for additional liner material
(2) potentially lower production costs.

The solid shell (CS-01) was chosen as the best solution for the performance evaluation of the advanced helmet.

Table 4. Results from linear impact tests

Helmet	Liner density [g/l]	Impact velocity [m/s]	Impact site	Impact anvil	Temperature [ºC]	Peak acceleration [g]
CS - 01 Carbon- Solid laminate	25	10	Front	Kerb	+50	319
	25	10	Crown	Flat	-20	230
	25	10	Rear	Kerb	+25	292
	30	7.5	Side R	Flat	+25	185
	30	7.5	Side L	Kerb	+25	173
CS - 02 Carbon- Sandwich	30	10	Front	Kerb	+50	235
	25	10	Crown	Flat	-20	242
	25	10	Rear	Kerb	+25	890
	30	7.5	Side R	Flat	+25	200
	30	7.5	Side L	Kerb	+25	186
Baseline current		10	Front	Kerb	+25	954
		10	Crown	Flat	+25	299

FULL GEOMETRY SURFACE FRICTION DEVELOPMENT

The aim of the surface friction development tests was to develop a low friction surface coating or system to reduce the tangential forces during an oblique impact. Two systems, identified during flat coupon testing, were evaluated together with an additional hardened metallic surface as detailed below.

1. Carbon composite (toughened epoxy matrix)
2. Sacrificial layer
3. Tungsten carbide (hardened metallic surface)

The surface friction tests were conducted in accordance with ECE Regulation 22-05 using a rigid free-motion headform of mass 4.7kg impacting onto the 15° abrasive anvil at 8.5m/s. Baseline tests were conducted on current full-faced GRP motorcycle helmets conforming to ECE Regulation 22-05. A summary of the results is provided in Table 5. The carbon composite shell and tungsten carbide surface significantly improved performance during the oblique impact tests, with frictional values of μ0.42 and μ0.39 respectively, compared to the baseline value of μ0.69. However, the sacrificial layer provided the greatest improvement with a friction coefficient of μ0.16, which represented a 77% percent improvement over the baseline result. The sacrificial layer was, therefore, chosen as the best solution for the performance evaluation of the advanced helmet.

Table 5. Results from surface friction tests
(ECE Regulation 22-05 limit for tangential force is 3,500N)

Helmet	Impact velocity	Impact anvil	Peak force [N]		
			Normal	Tangential	Friction
CS-01 Carbon shell with toughened epoxy matrix	8.5m/s	15° abrasive	2640	1118	0.42
CS-02 Carbon shell with sacrificial layer	8.5m/s	15° abrasive	2066	323	0.16
CS-01 Carbon shell with Tungsten carbide layer	8.5m/s	15° abrasive	3162	1250	0.39
Baseline helmet Full-faced GRP to BS6658A (average)	8.5m/s	15° abrasive	2874 2709 3187 2455 (2806)	1890 2000 2060 1806 (1998)	0.66 0.74 0.65 0.74 (0.69)

PERFORMANCE EVALUATION OF ADVANCED HELMET PROTOTYPE

The protection provided by the advanced helmet was assessed by comparing the impact performance of the advanced helmet with that of current motorcycle helmet designs conforming to ECE Regulation 22-05. This was achieved by performing both linear and oblique impacts with the helmets fitted with a Hybrid II headform instrumented with a nine-accelerometer array to measure linear and rotational accelerations. The linear impact tests were conducted onto the kerb and flat anvils as prescribed by ECE Regulation 22-05 with impact velocities up to 10m/s. The results from the linear tests were used to characterise the relationship between impact velocity and peak linear acceleration. The oblique impact tests were conducted onto the abrasive anvil as prescribed by ECE Regulation 22-05 (Method A) and additional tests were conducted using a variety of impact conditions established by the COST 327 replication programme, to simulate real accidents.

The results from these tests were analysed, as described below, to determine the response of both helmet designs in terms of AIS injury severity for a given impact severity. Because an impact to the head induces both linear and rotational motions, it was necessary to develop a method of assessing the performance and protection provided by the helmet with regard to both mechanisms. The GAMBIT assessment criterion was chosen for this study because it considers both linear and rotational motions and allows both impact components to be combined to give an indication of injury severity[1]. Although the COST 327 report found that the relationship between GAMBIT and AIS was low ($r^2 = 0.0751$), the replication data was reviewed and results from motorsport accident replication tests were included. This analysis produced a correlation coefficient of 0.57 ($r^2 = 0.3214$). It should be noted that the fatal cases were not included in this study. The following section describes the methodology for comparing the performance of the current and advanced helmets in terms of AIS injury outcome.

The relationship between impact velocity and peak linear acceleration, shown in Figure 2, was determined using test data from helmet tests onto rigid anvils. The advanced helmet was designed to provide protection during normal impacts up to 10m/s onto the rigid anvils compared with 7.5m/s for current helmets. The results show that the advanced helmet provides similar protection to the current helmet up to approximately 7m/s (normal impact velocity). At higher velocities the protection provided by the advanced helmet is considerably increased.

The advanced helmet was designed to provide improved protection during oblique impacts by having a very low friction outer surface. Figure 3 shows the relationship between linear and rotational accelerations for both current and advanced helmets based on the results from the ECE Regulation 22 (Method A) tests and the accident replication tests. The figure also shows a linear regression between the two parameters. It can be seen that the advanced helmet achieves

[1] The analysis needed such a relationship in order to carry out the risk of injury reduction analysis. In the absence of other combinational criteria, GAMBIT was used.

considerably lower rotational accelerations for a given linear acceleration. The results from Figure 2 and Figure 3 were combined to provide a relationship between equivalent normal impact velocity and peak rotational acceleration (Figure 4). It can be seen that the advanced helmet provides slightly improved protection up to approximately 7m/s and significant improved protection for higher impact speeds. The accident replication results, for the current helmet, were further analysed by plotting the normal impact velocity component against the peak rotational acceleration. The equation of the line of best fit was found to be $y = 1230.9x^{1.362}$. This line, as presented in Figure 4, was found to very closely agree with the rotational acceleration response curve for the current helmet and, therefore, was considered to support the validation of this methodology.

The relationship between impact velocity and GAMBIT results was determined by combining the results from Figure 2 (linear acceleration) and Figure 4 (rotational acceleration) using the equation below (see Figure 6).

$$GAMBIT = \sqrt{(g/250)^2 + (rad/s^2/10{,}000)^2}$$

The relationship between impact velocity and AIS (Figure 6) was determined using the results in Figure 5 and the following expression which was established from the analysis of accident replication data;

$$AIS = 2.0273 Ln(GAMBIT) + 2.0933$$

The results in Figure 6 can be used to compare the performance of the current and advanced helmets in terms of AIS injury outcome. Based on this study, it was possible to estimate the injury reduction benefits of the advanced helmet for those accident types where it was considered that an improved helmet could reduce the level of head injury. The following AIS injury reductions were used for the next part of this study.

- AIS 6 injuries reduced to AIS 4
- AIS 5 and 4 injuries reduced to AIS 3
- AIS 3 remain AIS 3 *
- AIS 2 remain AIS 2 *
- AIS 1 remain AIS 1 *

** although the AIS 1, 2 and 3 levels are shown to be reduced with the advanced helmet (Figure 6), the reductions were less than one whole AIS level. And, therefore, for the purpose of this study it was considered that the advanced helmet would provide the same injury outcome for these accidents.*

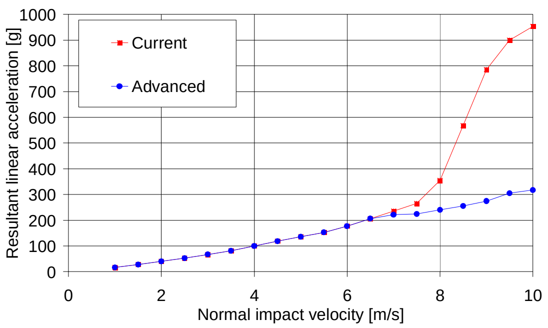

Figure 2. Relationship between impact velocity and linear acceleration for current and advanced helmets

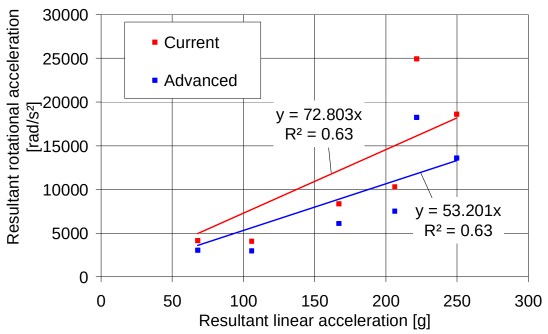

Figure 3. Relationship between linear acceleration and rotational acceleration current and advanced helmets

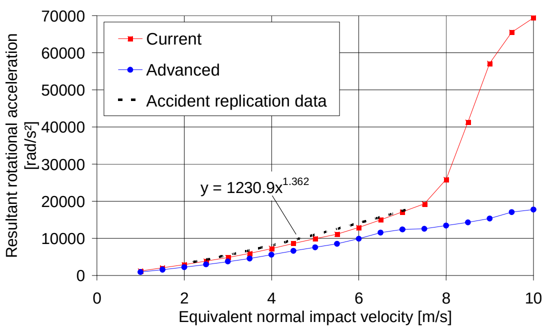

Figure 4. Relationship between impact velocity and rotational acceleration for current and advanced helmets

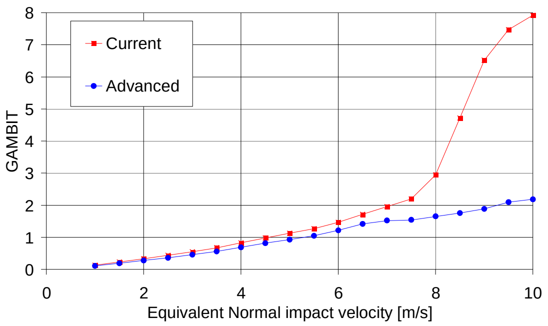

Figure 5. Relationship between impact velocity and GAMBIT for current and advanced helmets

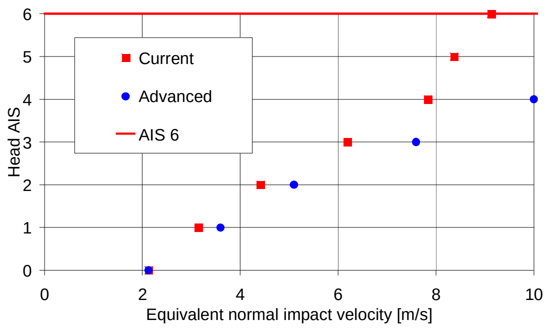

Figure 6. Relationship between impact velocity and AIS injury severity for current and advanced helmets

INJURY REDUCTION ANALYSIS

Assessment of benefits

Number of casualties who may benefit from an improved helmet - In order to evaluate the number of motorcyclists that may potentially benefit from an advanced helmet it was necessary to examine the national accident data. Table 6 indicates the number of Two-Wheeled Motor Vehicle (TWMV) casualties, by casualty severity, for the years 1999 to 2002 [6].

For the purposes of the cost benefit analysis the mean casualty severity values (1999-2001) were used. COST 327 [1] accident data analysis has suggested that 81.3% fatal, 67.9% serious, and 37.7% slight injured riders sustained head impacts which corresponded to 470 fatal, 4,493 serious and 7,744 slight.

Table 6. Motorcycle casualties (1999-2001; RABG 2002 [6])

Casualty severity	1999	2000	2001	1999-2001 (mean)
Fatal	547	605	583	578
Serious	6,361	6,769	6,722	6,617
Slight	19,284	20,838	21,505	20,542

It was important to consider specifically the cases for which head was the most severely injured body region as these cases would benefit most from an improved helmet design. Based on data presented by Chinn [7], the head was the most severely injured body region in 80% of fatal and 70% of serious cases where a head impact was sustained, which corresponded to 376 fatal and 3,145 serious cases. It was estimated that the proportion of slight injuries where the head was the most severely injured body region was 60% corresponding to 4,647 cases. A summary of these results is provided in Table 7 below.

Table 7. Annual number of motorcycle accidents where riders or pillions suffered head injuries

Casualty severity	All casualties (1999-2001) (A)	Casualties with head injury (B)	Casualties with head injury *and head most severely injured region* (C)
Fatal	578	470 (81.3% of A)	376 (80% of B)
Serious	6,617	4,493 (67.9% of A)	3,145 (70% of B)
Slight	20,542	7,744 (37.7% of A)	4,647 (60% of B)

AIS distribution of casualties who may benefit from an improved helmet - The AIS (AAAM, 1990) distribution of those casualties whose head was the most severely injured body region was estimated by reviewing 158 cases from the COST 327 accident replication project for which detailed accident and injury data has been analysed. The AIS injury distribution is presented in Table 8, below.

Table 8. Head AIS injury distribution for fatal, serious and slight motorcycle casualties

	Head AIS						
Casualty severity	6	5	4	3	2	1	All
Fatal*	33.3 %	33.3 %	22.2 %	11.1 %	0 %	0 %	100 %
Serious*	0 %	13.0 %	13.0 %	17.4 %	56.5 %	0 %	100 %
Slight†	0 %	0 %	0 %	0 %	12 %	88 %	100 %

* based on analysis of 158 cases from COST 327

† based on COST 327 final report

The AIS distribution (Table 8) was combined with the estimated number of casualties whose head was the most severely injured body region (Table 7) to derive the data presented in Table 9 below. The numbers of slight casualties in Table 9 were distributed according to data contained within the COST 327 final report which indicated that 88% of slight injures are AIS 1 in severity; the remainder of injuries were assumed to be AIS 2 injuries.

Table 9. AIS injury distribution for casualties with head most severely injured body region

	Head AIS						
Casualty severity	6	5	4	3	2	1	All
Fatal	125	125	84	42	0	0	376
Serious	0	409	409	547	1,777	0	3,145
Slight	0	0	0	0	558	4,089	4,647
All severities	**125**	**534**	**492**	**589**	**2,335**	**4,089**	**8,167**

Further analysis of the Cost 327 cases was made to determine whether or not the advanced helmet design would have provided improved protection to the wearer. The impact kinematics, impact type and impact mechanisms were considered, including an assessment of the linear and rotational injury potential. It was important to consider both the type and the severity of the impacts to determine which cases exceeded the protective capability of even the advanced protective helmet. Other cases involved impacts with aggressive structures or impacts through the visor that would not be protected by the advanced helmet. Table 10 presents a summary of this analysis with an estimate of the proportion of cases of each AIS severity that may have benefited from the advanced protective helmet.

Table 10. Proportion of cases† for which an advanced helmet may provide additional protection.

	Head AIS					
Casualty severity	6	5	4	3	2	1
Fatal	16.7 %	66.7 %	100 %	100 %		
Serious		100 %	100 %	75 %	92 %	
Slight					92 %	40 %

† *cases with head injury and head most severely injured region*

The values in Table 10 were combined with the values in Table 9 to provide an estimate of the number of casualties that may have had an improved injury outcome with the advanced helmet. This calculation assumes that every motorcycle rider, irrespective of factors (such as rider age, motorcycle make or model and engine capacity) is equally likely to be involved in an accident. These results are presented in Table 11.

Table 11. Number of casualties where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Casualty severity	**Head AIS**						**Total**
	6	5	4	3	2	1	
Fatal	21	84	84	42			**230**
Serious		409	409	410	1,635		**2,863**
Slight					513	1,636	**2,149**
All severities	**21**	**492**	**492**	**452**	**2,148**	**1,636**	**5,241**

Thus, if all motorcycle riders wore helmets to the performance specification of the advanced helmet, there is potential to improve injury outcome for 230 fatal, 2,863 serious and 4,647 slight per annum (see Table 11). The next part of the analysis was to quantify the *magnitude* of benefit that would be afforded by the advanced helmet. A summary of this analysis is provided in Table 12 below.

Table 12. Comparison of AIS injury outcome for current and advanced helmet designs

AIS current helmet	AIS advanced helmet†
6	4
5	3
4	3
3	3
2	2
1	1

† AIS injury severity for those accidents where it was considered that the improved helmet may improve the injury outcome

Assessing the injury distribution for the advanced helmet - Using the AIS injury reduction levels presented in Figure 6 (summary in Table 12) it was possible to consider those accidents where an advanced helmet would have benefited the rider (Table 11) and determine the overall level of injury reduction. Table 13 shows the AIS distribution for both current and advanced helmets, assuming the advanced helmet had been worn for all the cases presented in Table 11. Table 14 shows the injury severity in terms of fatal, serious or slight, based on the values AIS values in Table 13. This analysis assumes that the distribution of injury severity (fatal, serious, slight) remains constant within each AIS classification for both current and advanced helmets.

The difference between the results in Table 14 and those in Table 11 represents the overall annual injury reduction that may be achieved with the advanced helmet, as shown in Table 15.

- The advanced helmet was found to have the potential of saving 94 lives and 434 serious injuries each year, approximately 20% and 7% respectively. If the same proportion of injury reduction could be achieved on European roads more than 1,000 of the 5,000 fatally injured riders and pillion passengers could be saved each year and a further 5,000 of the 70,000 serious injuries could be prevented.

Table 13. AIS severity distribution for current and advanced helmets†

	AIS						Total
AIS distribution	6	5	4	3	2	1	
Current helmet	21	492	492	452	2,148	1,636	5,242
Predicted Advanced helmet	0	0	260	992	1,725	2,265	5,242

† for those cases where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Table 14. Injury severity distribution assuming the advanced helmet had been worn†

	AIS						Total
Casualty severity	6	5	4	3	2	1	
Fatal	0	0	44	92	0	0	136
Serious	0	0	216	901	1313	0	2,429
Slight	0	0	0	0	412	2265	2,677
All severities	0	0	260	992	1,725	2,265	5,242

† for those cases where the head was the most severely injured body region and the accident conditions were such that an advanced helmet may have provided additional protection

Table 15. Estimated annual injuries for current and advanced helmet design

	Current	Advanced	Reduction
Fatal	230	136	94
Serious	2,863	2,429	434
Slight	2,149	2,677	-528
All	5,242	5,242	0

COSTS AND MARKET PENETRATION

The advanced helmet is produced using relatively expensive materials and processes. The cost for each prototype carbon shell was approximately £1,000 including materials, production process and autoclave time etc. It was, therefore, important to consider the key cost issues if such helmets were to be mass produced to achieve significant sales penetration.

It was estimated that if such helmets were produced in medium volume, the production costs could be reduced to approximately £200, with a corresponding minimum retail price of £300 – around £150 more than a typical current helmet.

This price would be competitive with high end market products and sales volumes of up to 10% per year may be achievable. According to the UK Department for Transport (DfT) figures, there were 760,000 licensed Two-Wheel Motor Vehicles (TWMVs) in Great Britain in 1999 [8] It was assumed that the average rider purchases a new helmet every five years, giving estimated annual helmet sales of 152,000 units. This is consistent with the number of new registrations for TWMV; 168,000 in 1999 [8] since a proportion of TWMV riders may purchase a new vehicle but already own a helmet.

If 10% of all new helmets sold conformed to the new level of performance, the fleet penetration of this new helmet would be 2% in year one, 4% in year two, 6% in year three, 8% in year four and 10% in year five (a total of 76,000 units sold by year five).

With a fleet penetration of 10%, the new helmet has the potential to save approximately 10 lives and 45 serious injuries each on roads in Great Britain. Nevertheless, it is understood that in order for future standards to be based on the performance of the new helmet, it would be desirable to significantly reduce the production costs.

A WAY FORWORD

Given the potential performance of new helmet technology, the DfT has prompted a collaborative research effort with like-minded partners to develop the test methods that will be needed to assess new advanced helmet designs.

A partial Regulatory Impact Assessment (RIA) has been prepared for the UK DfT which suggests that a consumer information scheme might be the most practical way to encourage the supply and uptake of advanced motorcycle helmets to work towards a 20% reduction in motorcyclist fatalities.

On this basis, TRL, using their experience of Euro-NCAP and Primary NCAP, are currently developing a possible consumer information scheme for motorcycle safety helmets. Initially, interest is being sought from key stakeholders and research partners with proposals being developed for discussion in a small technical working group and with industry. Pilot assessments on a range of current and advanced helmets will be reported in a media-friendly format to complete the delivery of a ready to implement scheme. The actual tests will be based on those in Regulation 22-05, but amended as appropriate to ensure that better helmets can be identified and the objectives of the scheme achieved. Details of this and earlier related work may be found on www.mhap.info.

Further work, including physiological performance, is being taken forward in a new COST project and it is hoped that the costs of advanced helmets can be reduced through an EC 6th Framework Programme project under consideration.

CONCLUSIONS

- An advanced prototype helmet has been developed by TRL and industry which exceeds the safety performance specified by COST 327, offering improved protection from both linear and rotational loadings to the head.

- This was achieved with a lightweight carbon composite shell fitted with an optimised high-efficiency expanded polystyrene energy absorbing liner and a low friction sacrificial shell surface.

- The advanced helmet has the potential to achieve significant safety benefits over a conventional motorcycle helmet. It was estimated that the advanced helmet has the capability to reduce AIS 6 injuries to AIS 4 and AIS 5 and 4 injuries to AIS 3.

- National accident data was analysed in conjunction with data from COST 327 and the TRL motorcycle accident replication programme. It was estimated that of the 578 motorcycle riders (or pillions) killed each year (during 1999 and 2000) 93 lives could be saved if all riders had been wearing the advanced helmet. And a further 434 of the 6,617 serious injuries could be prevented.

- If the same proportion of injury reduction could be achieved on European roads, more than 1,000 of the 5,000 fatally injured riders could be saved each year and 5,000 of the 70,000 serious injuries could be prevented.

- It was estimated that the cost of producing the advanced helmet may be in the region of £200 per helmet. Thus a minimum retail price would likely be £300 - approximately £150 more than a typical current motorcycle helmet.

- Given the potential of the new helmet technology and performance, the DfT is leading a collaborative research effort to produce the test methods that could be used to assess the protection offered by new advanced helmet designs.

- A proposal has been submitted for an EC 6th Framework Programme project to take the current work forward and minimise the cost of advanced motorcycle helmets.

ACKNOWLEDGEMENTS

The DfT and TRL would like to thank all members of COST 327 for their valued contributions, without which this research would not have been possible.

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DEVELOPMENT OF PRE-CRASH SAFETY TECHNOLOGY FOR LARGE TRUCK

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Paper Number 05-0298

ABSTRACT

As one of the key technologies to improve safety of large trucks, pre-crash safety technology (PCS) was studied. PCS is the system which automatically activates brake when a collision is unavoidable.
From the accident analysis, it was found that collision to the stationary vehicles and accidents on expressways shall be considered in the study. To cope with the accidents on expressways where collision speeds are usually high, the PCS system needs to detect the objects and apply brake from a long distance. To achieve this, sensor shall be tuned to enable the sensing from long distance, however, generally this can result in difficulties to clearly divide real objects on the road and something on the road side especially at curves. If we can limit the activation of the system only on expressways, there is possibility that this can be improved. Because on the expressways, traffic lanes are wider and thus road side objects are a little far from the center of the traffic lane, and radius of curves are more than certain value. Activation timing of the brake shall be decided so that the driver does not place too much trust in the system. For this reason, the brake shall not be activated when there is certain possibility that the collision is avoidable.

INTRODUCTION

Fatal accidents on which large trucks are responsible, rear-end collisions to passenger cars are most common. Over the half of this rear-end collisions occurred on expressways and usual cause of the accidents are large truck driver's not looking ahead carefully or misjudgment.
To reduce the rear-end collisions, distance warning system and adaptive cruise control system which keeps safety distance to the preceding vehicle were developed and put into practical use.
In case that the collision is not avoidable, systems which reduce collision speed and mitigate the damage to the passenger cars are desirable. Impact energy of the large truck is big because of the vehicle mass and if we could reduce the impact speed, it can result in large reduction of impact energy and can mitigate the damage considerably.

ACCIDENT ANALYSIS

Based on the accidents statistic data of the year 2002, fatal accidents on which the large trucks are responsible were analyzed. Here large truck is with the GVW of more than 8 tons and number of fatalities includes only the death within 24 hours after the accidents. In large trucks to four wheel vehicle accidents, rear-end collision is most common and it accounts for 59% (See figure 1).

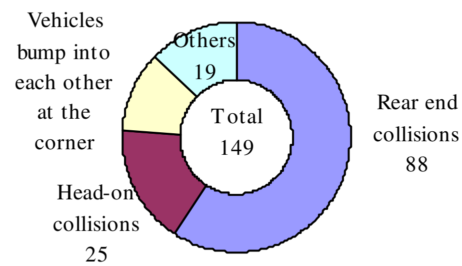


Figure 1. Fatalities in large trucks to four wheel vehicle accidents responsible to large trucks (in 2002)

Within the rear-end collisions, fatalities in passenger car occupants make up the largest shear. The most common case is the ones that the stationary cars are hit from behind (See figure 2). When classified by road types, almost 50 % of the rear-end collision occurred on expressways (See figure 3). Fatality rate of passenger car occupants in rear-end collision on expressways is eight times higher compared to that of on general roads.

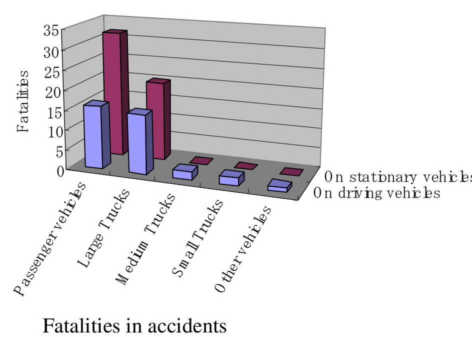
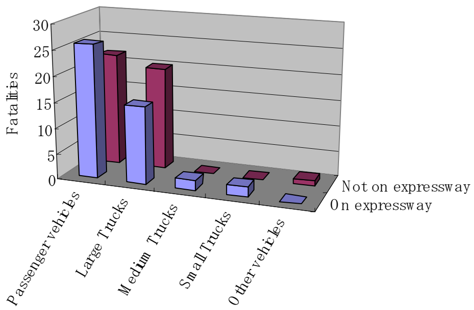


Figure 2. Fatalities in rear-end collisions (in 2002), classified by stationary and on driving vehicles.



Fatalities in accidents

Figure 3. Fatalities by rear-end collisions (in 2002), classified by on highway and not on highway.

Figure 4 shows one example of accidents where a large truck collided to the rear of passenger car. Eleven vehicles were involved and four persons in passenger cars died. Accidents of large truck have possibility to result in loss of many lives and loss of economic activities. It is strongly desired to reduce these accidents or reduce damages in these accidents.

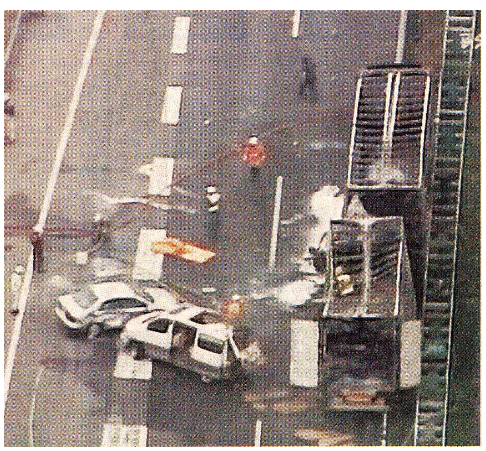


Figure 4. One example of accidents; large truck collided to passenger cars on a highway (quoted from Asahi Shinbun)

From the accident analysis above and general understanding of the operation of the large trucks, it was concluded that the following points shall be considered in the study of PCS for large trucks.

1) Collision to stationary vehicle
2) Rear-end collision on expressways

OBSTACLE DETECTION

When the system targets the activation of the brake with stationary vehicle ahead, obstacle detection technology which can clearly separate the objects on the road and road side objects is the key. If the target of the system is just the moving preceding vehicle ahead, it is easy to separate it from the road side objects, by utilizing the speed of own vehicle and exclude the road side objects as objects which have relative speed equal to the vehicle speed. In case we need to treat stationary vehicle, development of new algorithm to detect only the objects on the road is necessary. An example of unwanted detection occurs when there are reflectors and other road side objects on curves. One idea to cope with this example is to use yaw rate of the vehicle and estimate the curvature of road ahead and add the information to the object detection algorithm.

To cope with the accidents on expressways where collision speeds are usually high, the PCS system needs to detect the objects and apply brake from a long distance. To achieve this, sensor shall be tuned to enable the sensing from long distance, however, generally this can result in difficulties to clearly divide real objects on the road and something on the road side. If we can limit the activation of the system only on expressways, there is possibility that this can be improved. Because on the expressways, traffic lanes are wider and thus road side objects are a little far from the center of the traffic lane, and radius of curves are more than certain value. To maximize the effectiveness of PCS system, study of how to extend the distance of obstacle detection shall be continued.

Some ideas to separate the stationery objects on the road and road side objects are to add the image processing, or to obtain information of road ahead from navigation system.

BRAKE CONTROL

Activation timing of the brake shall be decided so that the driver does not place too much trust in the system. For this reason, the brake shall not be activated when there is certain possibility that the collision is avoidable. Figure 5 shows the guideline of brake activation in the system in Japan. In the guideline, the brake can only be activated when the collision cannot be avoided neither by braking or steering maneuver.

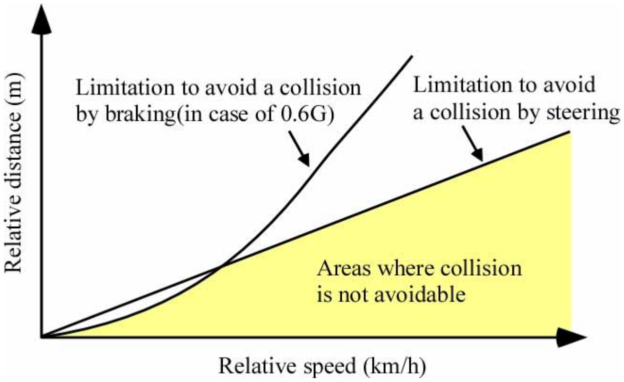


Figure 5. Guideline for brake activation

CONSIDARATIN ON SENSORS

Table 1 shows comparison of sensors for object detection. For PCS system, millimeter wave radar must be the current choice because of its environmental robustness compared to infrared laser sensor.

Table 1.
Comparison of sensors

Items	Infrared raser sensor	Millimeter wave radar	Imaging sensor
Detectable objects	Laser reflector or Assembly of tail lights	Mainly metals	Edges of contrast on the screen
Maximam distance of detection	≥120m	≥150m	30m - 60m
Detectable maximam relative speed	≥100km/h	≥100km/h	≤100km/h
Environmental robustness	✓Fog Rain Light snow	✓Fog ✓Rain ✓Light Snow	

SYSTEM CONFIGURATION

Figure 6 shows an example of Pre-crash safety system configuration. Components of the system are millimeter wave radar for object detection, yaw rate sensor for vehicle movement information, computer for estimation of possibility of collision, human machine interface for warning to driver, and Electronic brake system for braking.

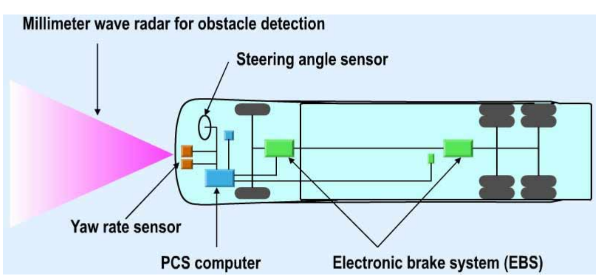


Figure 6. System configuration

CONCLUSION

Pre-crash safety technology for large truck was studied and following points became clear.

1) From the accident analysis, collision to the stationary vehicle and accidents on the express way shall be considered to have effective system.
2) For obstacle detection, development of ways to separate objects on the road and road side objects is the key. Millimeter wave radar together with yaw rate sensor can improve the accuracy to certain extent. If we can limit the activation of the PCS system only on the expressway, obstacle detection can have better performance.
3) Activation timing of the brake shall be decided so that the driver does not place too much trust in the system. Influence to the stability of the vehicle shall be also considered.

Accidents of large trucks can result in many loss of human lives and loss of economic activity. Prevention of the large truck accidents is highly expected. However, human error can not be perfectly eliminated. From this point of view, technology which mitigates the damage in case of accident is necessary. The pre-crash safety technology is a key technology to mitigate damage in large truck accident. Development of safety technology to prevent the occurrence of accidents and to minimize the damage in accidents shall be continued until the accident free society would be finally realized.

THREATS FOR LIMITATIONS OF VISUAL TRANSMISSION CAUSED BY LACK OF ADAPTATIONS TO EXISTING NEEDS FOR HEAVY TRUCK'S CABIN CONSTRUCTION

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ABSTRACT

In this report are presented results of research concerning widespread and spacing zones around the vehicle (truck categories: N1, N2, N3, i.e. small, medium and heavy) that are visual field of a driver and are bounded by a cabin construction with its equipment. Research method described in UN ECE Regulation No. 46 referring to assessment of provision of visibility by vehicle's mirrors was used in discussed research.

Performed analysis is due to critical situations for tested vehicle. Example analysis was placed on extended intersections with left turn, angular crosscut intersections and on angular railway crossing. A discussed example pointed out that driver has no possibility to observe zones of road, which are crucial for a safe movement of a vehicle. Analysis was performed for vehicles being currently in use and meet current regulations and also more strict regulations, which will be in force due to new European requirements.

For vehicles equipped in accordance to mandatory requirements author pointed out that one of possible direction of decreasing risk of a collision or an accident is to decrease limits in visual transfer of driver – vehicle – surrounding system. It is necessary to consider some modifications of construction and also form of surrounding due to some vehicle and driver constraints.

Regulations compulsory up to now were stringent enough. Complete equipment of vehicles referring to observation possibility were much more lean. Zones that driver can observe in older vehicles are distinctly smaller so threats in older vehicles are much more evident.

This report presents propositions of extending possible observation zones. Also it presents results of investigations for estimation of extended observation zones and of their arrangement after proposed changes in vehicles of different categories. Proposed modifications for in use vehicles and for requirements of vehicle type approval are very basic as a first step.
Keywords: vehicle safety, visibility, proposals.

INTRODUCTION

Although a vehicle meets all requirements referring to visibility, in many cases, not only in the Polish road conditions, a driver has no possibility to take advantage of those car features. Lack of adaptation for surrounding configuration due to limitations of vehicles' cabin construction is a main cause of above mentioned problem.

Advance observation by the driver of some crucial parts of surrounding area is the most important term in case of quick reaction and meeting the possible threats. Factors which affirmatively affect the way of gaining information and which are decisive in case of driver comfort can reduce the level of accident threat.

In some particular roads configuration (e.g. angular crosscut intersections or railway crossings – See Figures 1, 2, 3) possibilities of observing of all area around the vehicle with truck category N1, N2, N3 are not sufficient to undertake proper decisions about continuing the trip safely.

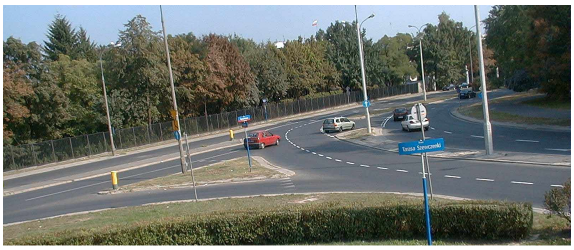


Fig. 1. Situation on the angular intersection with reduced visibility on the right side of the vehicle.

Fig. 2. Commercial vehicle with category N1 at the angular crosscut intersection with tram railways

Fig. 3. Commercial vehicle with category N1 at the angular crosscut intersection with railways

Passenger vehicles are equipped with windows on all sides which gives a driver possibility of observing the whole surrounding of the vehicle. In such condition a driver of the passenger vehicle after turning his head right can observe area through the window in the rear right door and through the rear window. Most of trucks behind the driver's seat have load-carrying space which is not transparent. Mentioned problem causes significant limitation to observation zones. It endangers driver's health due to probable collision effects. The driver in such situation has no possibility to observe surrounding of the vehicle in necessary range.

METHODS

Problem identification was carried out during comparative test of two vehicles: Polonez Caro with M1 category (See Figures 4 and 5) and Polonez Truck with N1 category (See Figures 5 and 6). In discussed problem we assume that front parts of both vehicles towards B pillars are completely the same (taking into account the area of glass surface and arrangement of non-transparent elements). While rear parts beginning from B pillars of those two vehicles are completely different. Assessed vehicles are representation of vehicle categories they belong to.

Fig. 4. Tested passenger vehicle - Polonez Caro

Fig. 5. View from the cabin of passenger vehicle – Polonez Caro

The Polonez Caro has glass surfaces on rear and side walls. The Polonez Truck (See Figure 7) has a barrier behind the first seat row. Behind that barrier is placed non – transparent closed load-carrying body.

Comparison of those two vehicles will allow to identify how large limitation of observing zones is in case of N1 category vehicles.

Fig. 6. Tested commercial vehicle - Polonez Truck

Fig. 7. View from the cabin of commercial vehicle - Polonez Truck

Vehicles of category N2 and N3 (middle and heavy commercial vehicles) also were tested in regard of the arrangement of visible and invisible areas. The vehicle which was chosen as a typical representative regarding vehicles with category N2 is Ford Transit with delivery-van body. The arrangement of all opaque and transparent elements of driver's cabin regarding problem of visibility is typical for vehicles of that category.

Fig. 8. Tested commercial vehicle – Ford Transit

Fig. 9. View from the cabin of commercial vehicle - Ford Transit

The vehicle which was chosen as a typical representative regarding vehicles of category N3 is a truck – VOLVO (See Figures 10 and 11). The arrangement of all opaque and transparent elements of driver's cabin regarding problem of visibility is also typical for vehicles of that category.

Fig. 10. Tested Volvo truck

Fig. 11. View form the cabin of Truck Volvo FH12

All tests referring to observing zones of a driver were conducted in accordance to methods described in Regulation No. 46 and 71 of ECE UN (Economic Commission for Europe of United Nations). Measuring devices used during research met all requirements stated in mentioned regulations [8], [9]. Results of conducted visibility tests are listed below.

RESULTS

Results of conducted test referring all transparent and opaque zones on the level of road surface are presented on Figures 12, 13, 14, 15. Grid lines scale is 1m. Brighter areas on all Figures are transparent zones. Dark areas are invisible. Blue areas present zones which driver can see in rear mirrors.

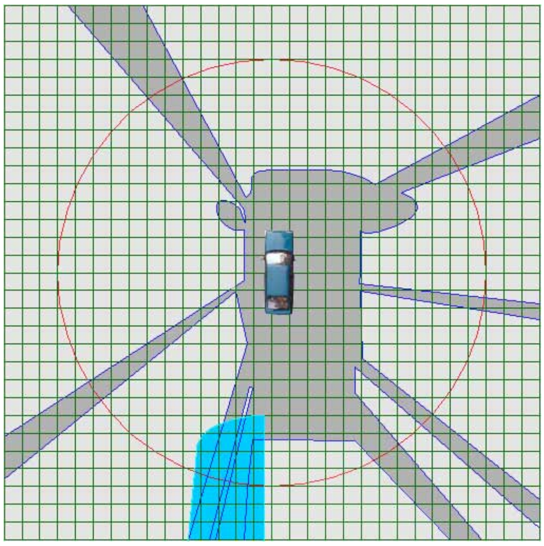


Fig. 12. Measured transparent zones – bright and invisible – dark, on the level of road surface – passenger vehicle Polonez Caro on research circle (diameter 24m)

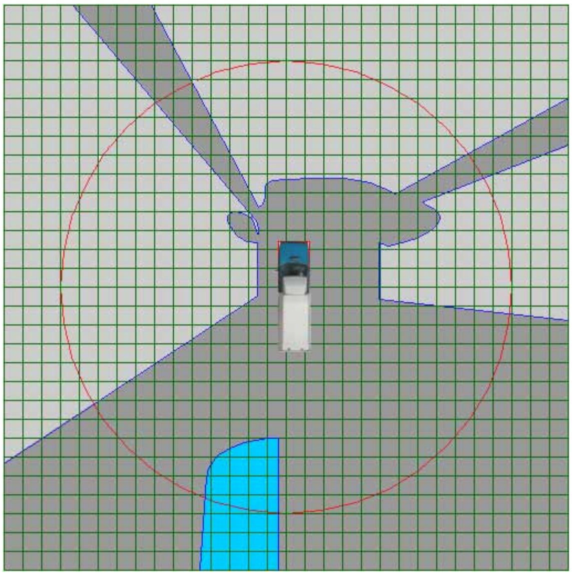


Fig. 13. Measured transparent zones – bright and invisible – dark, on the level of road surface – commercial vehicle Polonez Truck on research circle (diameter 24m)

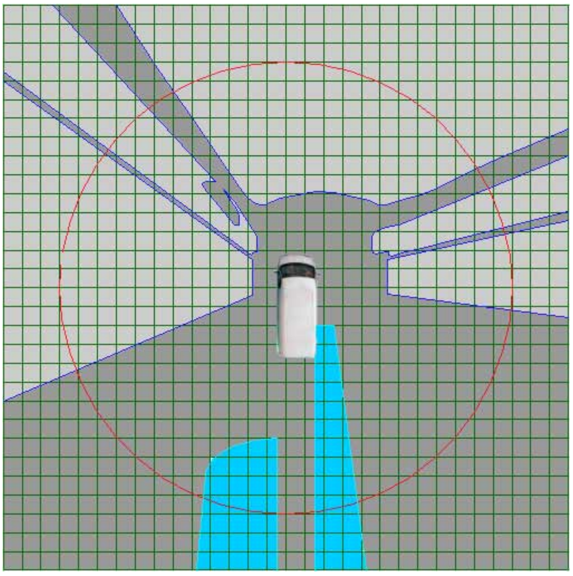


Fig. 14. Measured transparent zones – bright and invisible – dark, on the level of road surface – commercial vehicle Ford Transit on research circle (diameter 24m)

Because of the construction, vehicle limits driver's visibility. There are also road configuration limits and its flap walls (See Figure 16).
Dimensions of visibility field are function of the angle α roads crosscut, distance S between vehicle on a side road and a main road and also angle γ between B pillar and eye-points of vehicle driver, according to (See Figure 17), (analogical angle from left pillar is indicated by β – (See Figure 18).

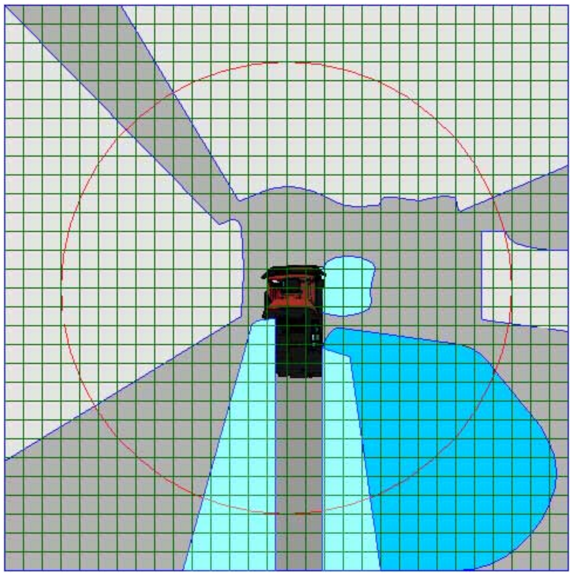


Fig. 15. Measured transparent zones – bright and invisible – dark, on the level of road surface – truck Volvo FH12 on research circle (24m diameter)

Analyzed problem was the influence of variation angle of a cabin right B-pillar, and distance between the car and the intersection and a crosscut intersection angle to length of the observed side main road section on the right side.

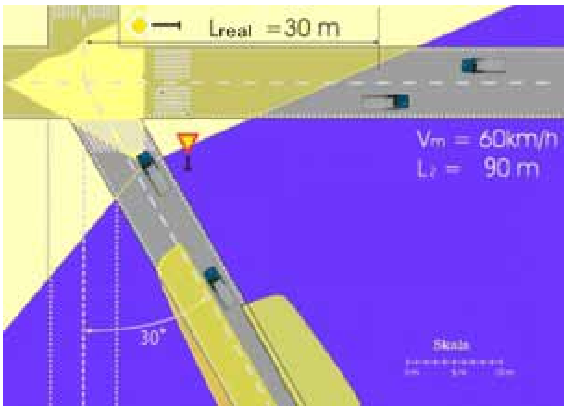


Fig. 16. Situation, stop on the angular intersection - approchement

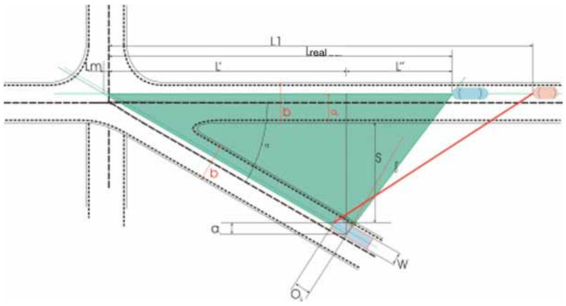


Fig. 17. Area of the real visibility (α = 30°, γ = 7°)

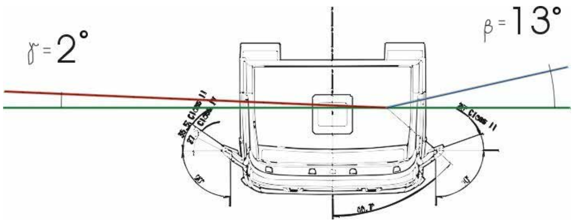


Fig. 18. Characteristic angles of vehicle cabin visibility field

Values, which dimensions knowledge is necessary to point out the range of visibility field are following:

$a = a_1 + a_2$

where $a_1 = \left(o_s + \frac{W}{4 \cdot tg\,\alpha}\right) \cdot \sin\alpha$ - distance between eye-points and a tangent crossing by extreme centre point on the front bumper

$a_2 = \frac{3}{4} b$, *where b – width of the road*

Vm – flow traffic speed – mean parameter mapping the speed of vehicles on free road traffic, used to determine road elements dimensions value, which on traffic safety consideration should be adjusted to this speed.

L1 – distance measured according to Figure 17, demanded by the traffic regulations while reaching an intersection with a measured speed road.

L2 – distance measured according to Figure 17, demanded by the traffic regulation while start moving to an entry at the intersection with a measured speed road.

$L_{rzecz} = L_{real.} = L' + L'' - L_m$ – real length of visible area from a vehicle, measured like an *L1*.

$L';L'';L_m$; - values on an intersection screen according to Figure 17.

- *S* – distance between vehicle on a side road and edge of main road,
- *b* – main road width,
- α – road's crosscut angle,
- *W* – car width,
- *Os* – distance between eye-points and perpendicular plane, crossing by a front outline of a vehicle,

$\alpha \in <25° \div 90°>$ – such range taken, because in situation with obtuse angles, driver does not have any limits from the right and from the left – he can put out his head through a left window. (it is unadvisable – driver switch his sight from a driving course),

$S \in <0m \div 20m>$ – maximal distance from the road edge, specified in the traffic regulations,

$\gamma \in <0° \div 10°>$ – such range taken according to testing of trucks category N1, N2, N3

$$L_{rzecz} = \left[S + a_1 + \frac{3}{4} b\right] \cdot \left[ctg\alpha + tg(\alpha + \gamma)\right] - \frac{b}{8 \cdot tg\alpha} \quad (1)$$

Formula (1) describes dependence of real visibility values - $L_{real} = f(s, \alpha, \gamma)$. The results of calculation are illustrated on graphs (See Figures 20, 22).

$$\frac{\partial L_{rzecz.}}{\partial S} = ctg\,\alpha + tg\,(\alpha + \gamma) \quad (2)$$

Formula (2) present sensitivity of visibility L_{real} to variable S describing position of vehicle reaching an intersection with a main road.

$$\frac{\partial L_{rzecz.}}{\partial \alpha} = \left(O_s \cdot \cos\alpha - \frac{1}{4} W \cdot \sin\alpha\right) \cdot \left[ctg\alpha + tg(\alpha + \gamma)\right] + \left(S + O_s \cdot \sin\alpha + \frac{1}{4} W \cdot \cos\alpha + \frac{3}{4} b\right) \cdot \left(-\frac{1}{\sin^2\alpha} + \frac{1}{\cos^2(\alpha + \gamma)}\right) + \frac{1}{8} b \cdot \frac{1}{\sin^2\alpha}$$
(3)

Formula (3) present sensitivity of visibility L_{real} to geometry of intersection (α angle between roads).

$$\frac{\partial L_{rzecz.}}{\partial \gamma} = \left[S + \left(O_s + \frac{W}{4tg\,\alpha}\right) \cdot \sin\alpha + \frac{3}{4} b\right] \cdot \frac{1}{\cos^2(\alpha + \gamma)}$$
(4)

Formula (4) present sensitivity of a visibility L_{real} to geometry of driver's cabin, represented by γ angle.

There is introduced concept of a relative visibility coefficient $(L_{rzecz.} - L_1)/ L_1$ or $(L_{rzecz.} - L_2)/ L_2$. The results of calculation are illustrated on graphs (See Figures 21, 23).

The results of sensitivity analysis are illustrated on graphs (See Figures 24, 25, 26).

The driver of a vehicle category N1, N2, N3, in spite of good visibility on the intersection, because of vehicle construction limits, has no chance to take full advantage of provided visibility field.

While reaching an intersection or starting moving on a such intersection (See Figure 19), driver instinctively becomes participant of "risk": he may cross an intersection or he will have an accident.

There are not predicted certain elements of safety system (concerning visibility), indispensable in extreme situations. Although driver satisfies the conditions, vehicle is authorized to traffic, road is according to traffic regulation – driver does not see enough for safe continuation of his ride.

Fig. 19. Situation on extended intersection with a turn to the left and visibility limited by cabin.

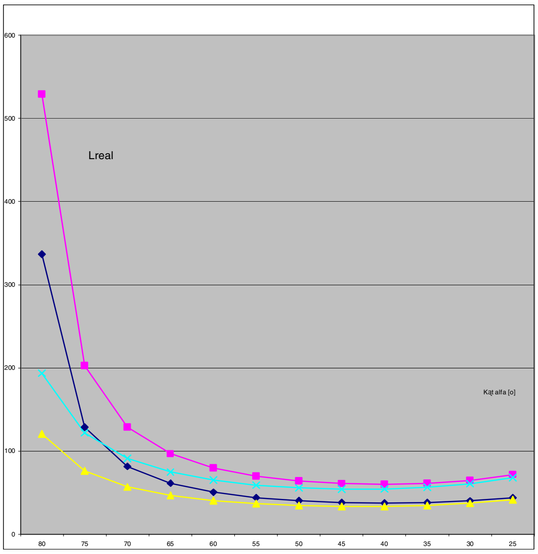


Fig. 20. Real visibility Lreal in function of alfa angle of roads crosscut – approaching, L1 = 120m, Vm = 60 km/h

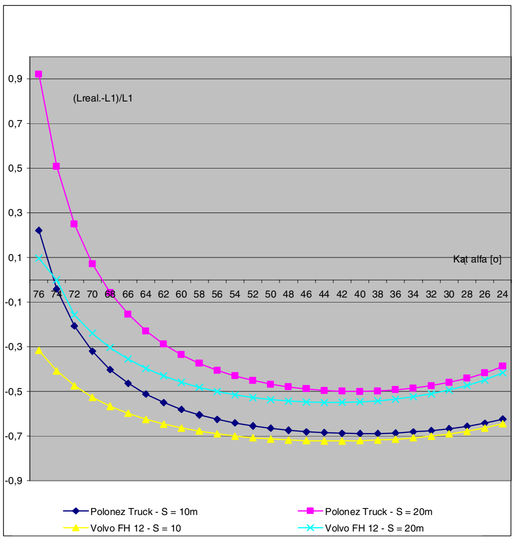


Fig. 21. Relative visibility coefficient (Lreal.-L1)/L1 in function of alfa angle of roads crosscut on intersection – approaching, L1 = 120m; Vm = 60km/h.

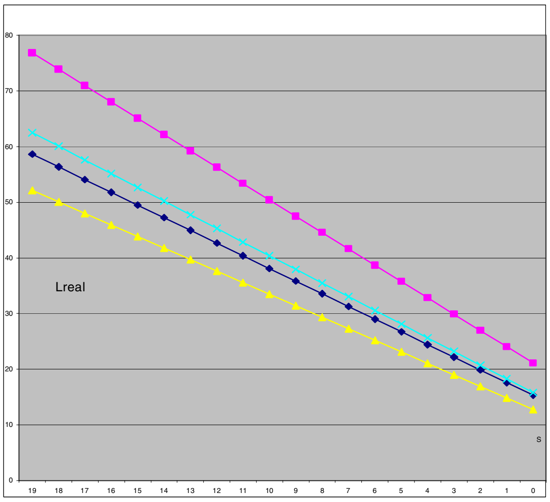


Fig.22. Real visibility on intersection Lreal in function of distance S from road edge – stop, L2 = 90m, Vm = 60km/h.

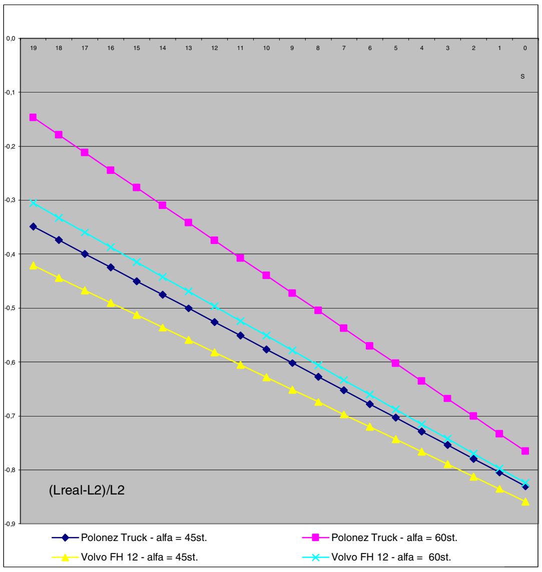
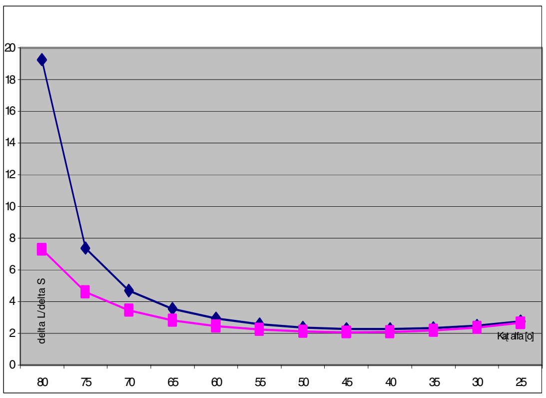


Fig. 23. Relative visibility coefficient on intersection (Lreal-L2)/L2 in function of distance S from road edge – stop, L2 = 90m, Vm = 60km/h.



Rys. 24. Sensitivity of visibility (delta Lreal/delta S) in function of alfa angle

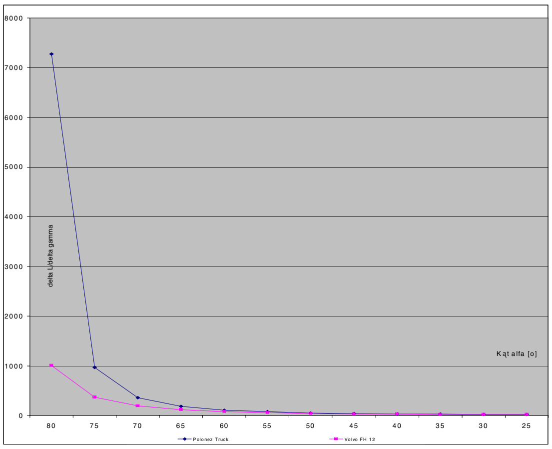


Fig. 25. Sensitivity of visibility (delta Lreal/delta gama) in function of alfa angle.

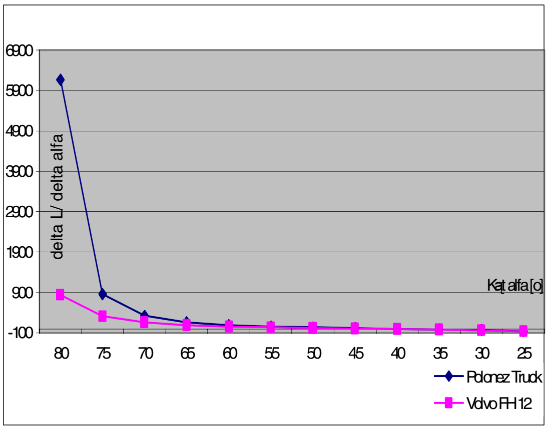


Fig. 26. Sensitivity of visibility (del Lreal/delta del. alfa) in function of alfa angle.

On the Figure 27 is illustrated simulation of real situation of truck on angular railway crossing. Light areas – visible to car driver. Dark areas – invisible. There are areas visible through car mirrors indicated by dark blue colour. Train is in invisible to car driver area.

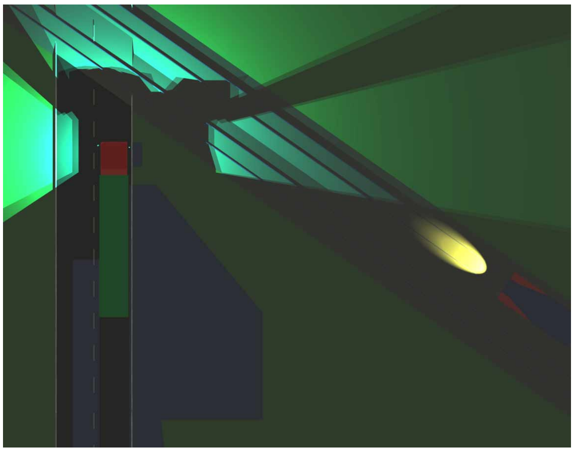


Fig. 27. Schema of the situation before accident.

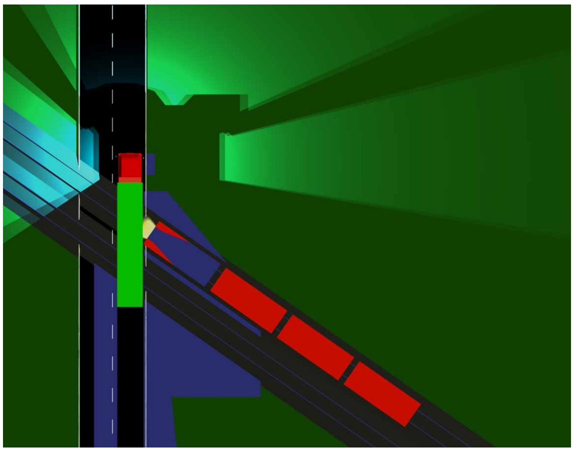


Fig. 28. Schema of the situation where truck is hit by train.

On the Figure 28 is illustrated moment of hit the truck by the train.
On the Figures 29 and 30 are illustrated damages of participants in accident: truck and train.

Fig. 29. Truck after accident.

Fig. 30. Train after accident.

DISCUSSION

From illustrated on the Figures 20 and 22 graphs follow that group of vehicles belonged to category N1, N2, and N3; in compare to passenger car has a large visibility limit, especially on the right side of vehicle. This characteristic is not noticed by traffic regulations authors.

Fig. 31. Extra spherical mirror in vehicle cabin

From obligatory regulations it is seemed that a such projected road does not cause formation of threat. Taking into consideration mentioned matters, projecting and existence of legal angular intersections (without additional elements of safety system) is the reason for accidents.

This consideration about safety of road traffic participants in aspect of visibility from vehicle driver's seat authorize to formulate the following observations and conclusions:

– problems of visibility from vehicle, although noticeable increase of meaning and still increasing formal – regulatory requirements, are still distant from solutions assuring liquidation of road traffic participants threats,

– Polish law standards concerning visibility matters require complex analysis and modification,

– deficiency of regulations follow mainly from lack of its complex treatment in the system Driver-Vehicle – Environment,

– visibility aspects do not have good lay out and are marginal treated in automobile literature.

Fig. 32. Mirror on a road of limited visibility

To help driver I propose to upply extra spherical mirror fixed in cabin on column A.

It allows to observe zone invisible up to now (See Figure 31).

Additionally is recommended to use large spherical mirrors on these intersections (See Figure 32), which enable observation of vehicle surrounding zones, which truck driver does not have possibility to observe without internal mirror.

CONCLUSION AND RECOMMENDATIONS

Indicated problems permit to understand the scale of projects with objective of road traffic safety system improvement. Significant part of these projects may provide meaningful effects – decrease of inhabitants threat and serious accidents indicators.

1. It is important to change urgently requirements of official certification regulations concerning vehicles construction and equipment in objective to assure driver enough visibility from a vehicle on angular intersections.

2. It is urgent to change regulations concerning necessary conditions of assurance of safety on angular intersections taking into account vehicles construction limits.

3. Analysis of sensitivity of real visibility on main road function demonstrate that aberration of α roads crosscut angle from right angle, cause a big variation of length of visible main road section $L_{real.}$ Sensitivity in the angle $\alpha < 75°$ is already not big, but in this case real visibility is distinctly less than required by regulations.
From above follows that α roads crosscut angle, absolutely should not be smaller than 75°.

4. It is appropriate to modify situation on angular intersections already existing with the purpose of eliminate possible threats of road traffic participants, for example by provide intersections with extra installations ensuring standard visibility from vehicles of different categories.

5. It is necessary to equip trucks with extra spherical mirrors located in a cabin, facilitating to driver environment observation.

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ENDANGERMENT OF PEDESTRIANS AND BICYCLISTS AT INTERSECTIONS BY RIGHT TURNING TRUCKS

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ABSTRACT

Inside urban areas some accidents are occurring between right turning trucks and bicyclists or pedestrians. The consequences are exceedingly severe if the truck runs over the vulnerable road user. This paper will help to improve the knowledge how these accidents happen. Matched to this countermeasures are shown and discussed to reduce the number and the severity of these accidents. This contribution is a compendium of the research assignment of the BASt (German Federal Highway Research Institute) given to DEKRA Accident Research named "Endangering of bicyclists and pedestrians at intersections by right turning trucks".

It includes remarks on the European regulations regarding the protection of pedestrians and bicyclists in case of collisions with trucks. This is followed by an overview of the existing standard of the knowledge documented in the literature. It includes among other things analysis of official statistics, in-depth accident analysis and description of measurements to solve the problem. The study contains the results of the in-depth analysis of 90 accidents with involved right turning trucks versus a pedestrian or bicyclist. Outcomes are coming from the pre-crash phase (e.g. kind of movement), and the impact (e.g. location of collision, speed and angle). One of the main problems is the insufficient field of view (blind spot) of the truck driver during the pre-crash phase. Results of blind spot analysis of two trucks with two different mirror systems will show possible improvements. The contribution will finish with a description of the developed safety concept concerning the analysed situation between right turning trucks and pedestrians or bicyclists.

INTRODUCTION

The diversity of transport tasks and the mobility required of, or commercially necessary for transport users make it impossible these days to conceive of a world without road transport. Unfortunately, it is also linked with negative consequences. These include not only the consumption of resources and pollution of the environment, but also road accidents and their resulting consequences.

In the year 2002 38,452 people lose their life every year as a result of traffic accidents in the European Union (Figures cover the EU region before the expansion of 1st May 2004). Between 14% (in France) and 46% (in Poland) of the total number of people who died in accidents on Europe's roads were unprotected road users (cyclists and pedestrians). In Germany the figure is 21%. The conflict between a truck and a cyclist or pedestrian may not be the most common situation encountered, but it is the most dangerous. The biggest and heaviest road user comes up against the smallest and weakest. Accidents in urban environments involving a truck turning right make up an important group in this accident scenario and formed the focus of a research project commissioned by the German Federal Highway Research Institute (BASt) carried out by DEKRA.

THE PROBLEM

In general the truck driver and cyclist travel unaffected by each other on their own parts of the road. The paths of the two groups cross at intersections, **Fig 1**. This crossing of paths of travel entail a corresponding risk of accident that involves a correspondingly high risk of injury for the unprotected road user. This situation raises a number of questions that were to be answered as part of the research project. What happens during these accidents? What are the problems for the road users involved? How can the accident figures and their consequences be reduced? Is the side protection of the truck able to prevent the unprotected road user from run over or reduce its incidence?

Compared to the car, the blind spots of a truck, i.e. the areas where the truck driver suffers impaired field of view, are considerably greater. The truck driver's field of view problems are, however, considerably greater than other road users are generally aware of. The truck driver is seated far higher up than the car driver. This means that although the eyes of the car driver are roughly located at the same level as the cyclist or the pedestrian, the eyes of the truck driver can be initially estimated as being 2.5 m above the road surface, the exact figure depending on the height of the truck, the seat position and the height of the seated driver. This higher position leads to numerous blind spots (dead angles) in front of, adjacent to and behind the truck. The ability of a person to be detected depends on the size of the person and his position in relation to the truck, **Fig 2**.

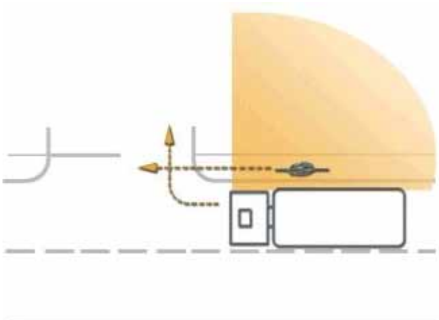


Fig 1: Example of a conflict scenario involving a truck turning right /1/

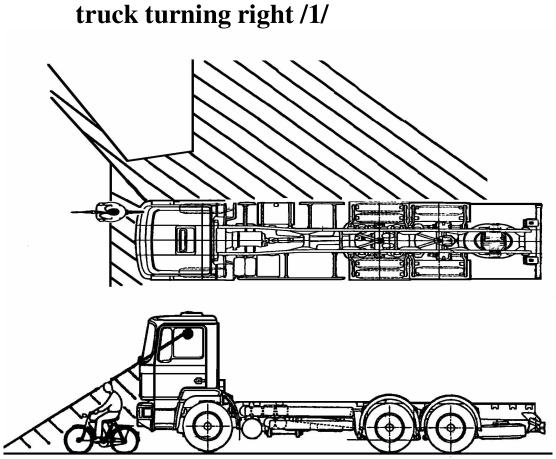


Fig 2: Examples of blind spots impairing the direct view, in a top-down view and as side view (object size up to 1.6 m)

The blind spots are the fundamental causes for the conflicts between the trucks and the unprotected road users analysed within this project. If the truck driver does not see the cyclist or pedestrian and turns right, a crash with the unprotected road user can be the result. The cyclists and pedestrians place their faith in the right of way laid down in the road regulations and assume that the truck driver can also see them in one of his numerous mirrors. This faith and the incorrect assumption about the truck driver's ability to see what is going on around the truck can end fatally if the accident causes the unprotected road user to end up under the truck and be rolled over by its wheels.

GENERAL ACCIDENT STATISTICS

In 2002 there were 362,054 accidents in Germany resulting in personal injury (API), of which 233,865 in urban area (64.6%) /3/. A total of 586,180 motor vehicles were involved in all APIs, of which 364,121 took place in urban area (62.1%). 21,633 goods vehicles (GV) were involved in APIs in urban areas. Goods vehicles include delivery vans and trucks with normal and special superstructures, articulated lorries and other traction engines. Agricultural traction engines are not included. This represents 5.9% of the motor vehicles involved in urban accidents. These GVs also include vehicles with a permissible total weight (PTW) up to a maximum of 3.5t. These vehicles have a fundamentally different vehicle superstructure and thus constitute different problems in an accident. This study was interested in the heavier GVs with ladder frame chassis and a correspondingly large space between the axles. Removing GVs with a PTW of a maximum of 3.5t leaves a percentage share of heavier GVs involved in urban APIs of between 2.3% and 2.8% (A more precise figure cannot be given because the PTW was unknown for some GVs.).

In 2002 official statistics recorded a total of 47,669 turning-off crashes. This represented 13.2% of all APIs. In built-up areas there were 37,766 turning off crashes, representing 15.7% of recorded urban accidents. The remaining 84.3% of urban APIs are covered by the other accident types.

Taking altogether, goods vehicles were involved in 2,920 accidents with cyclists and 1,580 cases with pedestrians in 2002. These 4,500 cases represent 2.2% of the urban APIs involving one or two participants.

Official statistics draw no clear distinction between the number of accidents involving GVs (>3.5 t) turning right and cyclists or pedestrians. A rough estimation of the absolute figure can be made by taking the total number of accidents between GVs and cyclists or pedestrians, the percentage of urban accidents in which the vehicle was turning right and the percentage of heavier GVs (>3.5 t) of all GVs. It must be borne in mind that the recorded number of turning off accidents covers right-turning scenarios that are not pertinent to this study. This means that in general terms only half (50%) of the turning-off accidents can be included in an estimation of the absolute number of cases.

If the figures and relations described above are taken as a basis, a figure of between 110 and 135 urban APIs between right turning GVs (>3.5 t) and cyclists/pedestrians is derived in line with the estimation in **Fig 3**. In 2002 there were 106 fatal urban crashes involving GVs and cyclists/pedestrians. Taking as a basis the same estimation as for the APIs in Fig 3, produces a figure of ten fatal crashes involving right turning trucks and an unprotected road user. This estimation for the APIs and for the accidents involving fatalities must be viewed with a certain degree of uncertainty because there is no way of ensuring that there are no distinct deviations from the respective parent population for the particular situation of right turning trucks. This could apply to fatal crashes in particular.

Many investigations look at accidents between truck and cyclists/pedestrians in general terms. Evaluation of the publications shows that the percentage of right turning accidents, insofar as this is given at all, is relatively low (Volvo 4 % /5/, Otte with 4.1% /7/ for a special turning off situation). Individual investigations such as Appel 1977 (/5/) quote a relatively high number of fatally injured unprotected road users losing their life in a crash involving a truck. The discrepancy with the estimations based on current figures can be traced, on the one hand, to the different accident situation prevalent at the time, which involved more fatally injured persons in this field, and, on the other, to the fact that the figures given there also include crashes that are not caused by the turning off situation.

Apart from the pure incidence of accidents the sources list other interesting aspects in this field of study. A Dutch study analysed the position of the opponent and the respective field of vision of the truck driver in the pre-crash phase. In 68% of the cases studied the pedestrian/cyclist was, at the point in time of perception by the truck driver, in a position that is not covered by the statutorily defined minimum view to ground level. It was also discovered that the injuries sustained in crashes with right turning trucks are particularly serious and frequently fatal /8/.

German studies from 1977 quote the accident figures current at the time. These relate to the Federal Republic of Germany as it then was and cite about 459 fatally injured persons per year for accidents involving a truck > 3.5 t both for pedestrians as well as for cyclists /5/. Studies of 18 truck/pedestrian and 14 truck/cyclist crashes revealed that in each case four pedestrians and four cyclists were hit frontally (13% of the opponents). Seven pedestrians and cyclists (22%) collided with the side of the truck. The reason why there was no run over in all cases is due

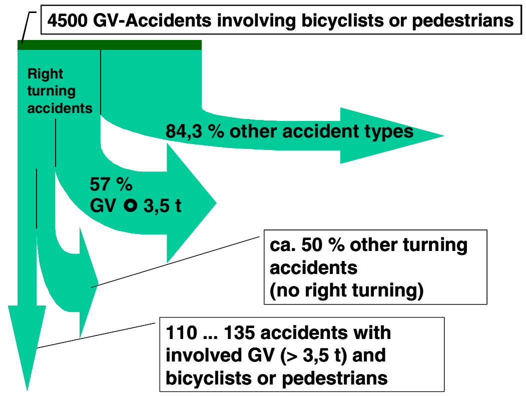


Fig 3: IRR figures /8/ derived estimation of the absolute figures of APIs with urban right turning GVs (> 3.5 t) and involved cyclists or pedestrians.

to the fact that the truck performed an emergency stop immediately following the initial contact.

An analysis of the accident data of the Medical University of Hanover (Medizinische Hochschule Hannover (MHH)) for the years 1985 to 1994 shows that cyclists, with 9.1 %, were after cars (41.2%) and other commercial vehicles (12.7%) the third most frequent opponent of a commercial goods vehicle /6/. Pedestrians were in fourth place with 4.4%. Cyclists most frequently collided frontally into the side of a commercial vehicle (35.6%). The analysis is based on the available data of all accidents there involving a commercial vehicle, without undertaking any pre-filtering such as, for example, as regards the type of accident or the location.

In a more recent study conducted by the MHH the accident inducing situation (accident type) involving a right-turning truck colliding with a cyclist on a cycle path (accident type 243, see **Fig 4**) came fourth in a table of accident types with 4.1% for commercial vehicles (≥7.5 t) /7/.

IN-DEPTH ACCIDENT ANALYSIS

The official road accident statistics /8/ can give a rough overview of the total number or the share of the accident situations of interest. In-depth data survey and analysis enable more thorough analyses. 45 individual cases involving collisions between unprotected road users and right-turning trucks were taken from a database of recorded cases held by DEKRA and the MHH, and studied in detail.

The turning trucks were nearly all involved in accidents between the period of 6 a.m. and 6 p.m. **Fig 5**, almost exclusively in daylight and virtually always (except for three cases) in dry weather

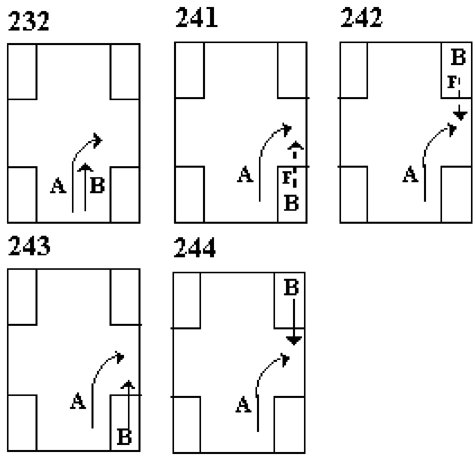


Fig 4: Pictogram of the most common accident types involving right-turning trucks and pedestrians/cyclists from the three-digit accident type catalogue /13/

conditions. The crashes under scrutiny took place during the working days Monday to Saturday. In more than 40% of the accidents studied, one person died during or following the accident, by far the greater percentage of these crashes involving a fatally injured person coming from the DEKRA data pool.

The unprotected road users involved in the accidents studied were predominantly cyclists (78 out of 90) and came from all age groups, **Fig 6**. Females are represented far more significantly among pedestrians/cyclists than males, **Fig 7**. This distribution of about 1 : 2 (men : women) does not match the distribution of cyclists in the official statistics (about 2 : 1).

There is a range of variants corresponding to the three-digit accident type catalogue /13/ for the accident-inducing critical situation between the right-turning truck and cyclist or pedestrian. The most common incidence in the accidents studied was the conflict between the right-turning truck and the cyclist travelling in the same direction along a separate path on the right-hand side of the road surface. (accident type 243; 71 % of the 90 accidents reviewed), **Fig 8**. The corresponding situation involving a cyclist on the same lane was significantly rarer (10%). As a consequence of their relatively low share of accidents involving pedestrians in the poll of accidents studies, accident types 241 and 242 (see also Fig 4) are only slightly represented.

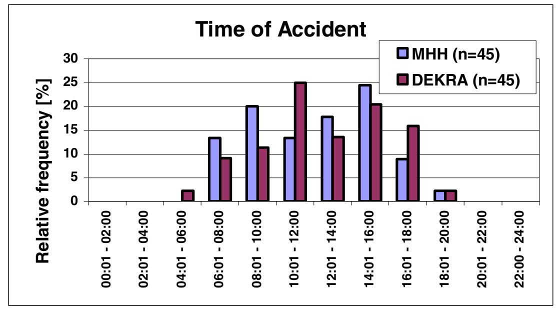


Fig 5: Time of accident of the accidents studied involving right-turning trucks

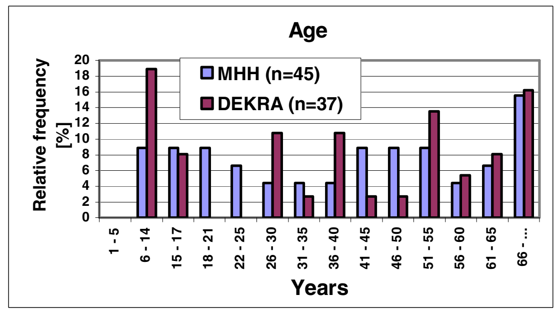


Fig 6: Age of involved pedestrians and cyclists

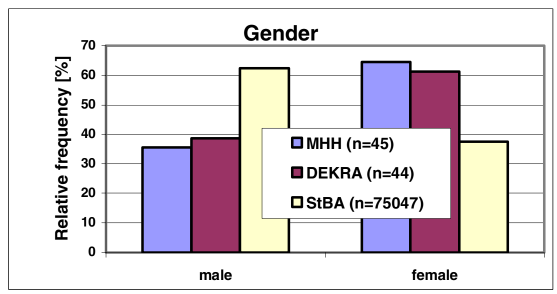


Fig 7: Gender of the involved pedestrians and cyclists

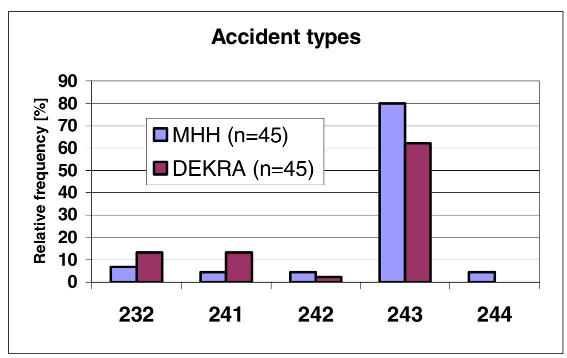


Fig 8: The most frequent accident types encountered (see also Fig 4)

Basically there are two fundamentally different behaviour patterns displayed by turning trucks before collision, **Fig 9**. One group was stationary before commencing the turning manoeuvre (at a traffic light or due to traffic conditions) in order to then accelerate from stationary and initiate the turning manoeuvre. The other group was in motion before decelerating to the required speed to initiate the turning manoeuvre. The consequences of the accident for the cyclist are more serious in the scenario where the truck began stationary. In this instance more than half (51%, **Table 1**) suffered fatal injuries whereas the figure for the other scenario totalled merely 31% (**Table 2**). The speeds determined for the truck and cyclist involved in the accident show a similar magnitude. This means there is virtually no relative movement between cyclist and truck. This fact which can also be found in the literature is of great significance as the following will show. **Fig 10** gives the basic relative movement of the cyclist vis-à-vis the truck for the seconds of the collision /6/. The cyclist does not leave the blind spot during this time.

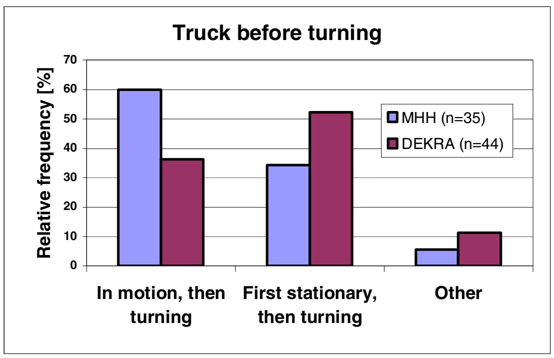


Fig 9: Movement behaviour of the truck in the accident before commencing the turning manoeuvre

	Slightly injured	seriously injured	killed	total
number	2	13	16	31
[%]	6.5	41.9	51.6	100.0

Table 1: Severity of cyclist injuries for a truck that is stationary before performing the turning manoeuvre, Source: DEKRA + MHH, each cover data of several years

	Slightly injured	seriously injured	killed	total
number	7	17	11	35
[%]	20.0	48.6	31.4	100.0

Table 2: Severity of cyclist injuries for a truck that is moving before performing the turning manoeuvre, Source : DEKRA + MHH, each cover data of several years

The accidents studied contain many pedestrians or cyclists that have been run over (62%). The initial impact of the cyclist/pedestrian took place for the most part in the front right-hand corner of the vehicle (57%), **Fig 11**. This area includes the right part of the front, the front right-hand corner and the right side of the front axle. Merely 7% of the pedestrians and cyclists collided for the first time with the truck in the area of the side guard (SG). The initial collision is merely the primary contact between pedestrian/cyclist and truck. This is usually followed by a fall down and one or more additional contacts. Of particular interest is the area of the vehicle in which the pedestrian/cyclist ends up under the truck. Depending on where the initial impact took place, it is followed by a run over. A study conducted in the Netherlands /8/ discovered that 62% of initial contacts take place on the right-hand side in front of the front axle.

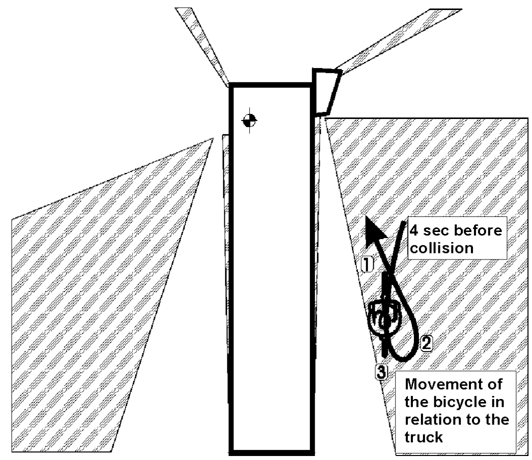


Fig 10: Principal relative movement of the cyclist in the accident in relation to the truck, /6/

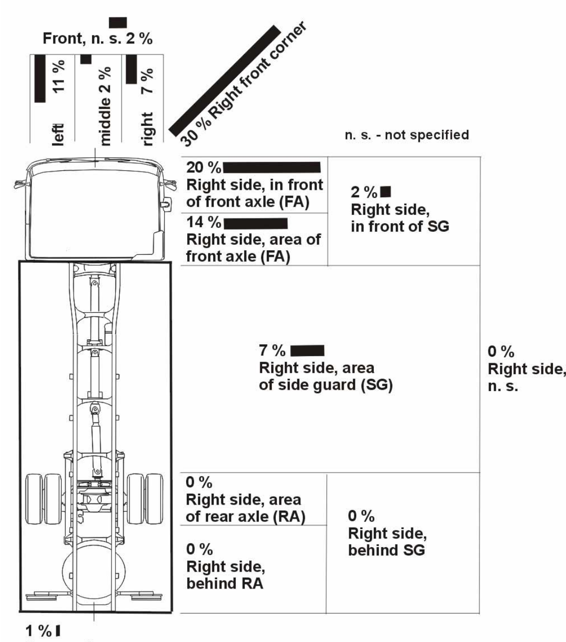


Fig 11: Area of the initial impact on the right-turning truck

In the accidents studied the persons did not inevitably end up under the truck where the initial impact took place. Depending on the specific nature of the impact constellation, the road user who fell down only ended up under the truck at a later stage. In the accidents studied 59% of the truck opponents ended up still in front of the front axle under the truck. A further 23% ended up in the immediate area of the front axle under the vehicle. Building site and municipal vehicles were involved particularly frequently in the accidents studied (46%). In the case of the building site vehicles this is partially attributable to the greater line of sight problems occasioned by greater height of the chassis and the frame of such a truck.

The frequency of the first contact points on the right front edge of the truck wasn't expected previously. This had given a decisive influence to the following project work. Therefore the main focus changed to primary safety.

THE PROBLEMS OF TURNING RIGHT OF TRUCKS

DRIVER

Not every truck driver is aware of the dangers and problems of turning right. In many regions of a country, for example, the percentage of cyclists of private traffic is very high, while in other regions virtually no cyclists are encountered. The figure depends on the population structure and the geography. Now if a driver only comes across cyclists and pedestrians very rarely on the roads in the region he knows well, he does not reckon on encountering them on roads he does not know well even though he is, in principle, aware of the problem presented by the situation. By the same token, however, cyclists and pedestrians also reckon on what is for them the accustomed behaviour patterns of drivers. This results in a higher risk of accident. The normal behaviour patters of road users and the state of expectation that this brings with it therefore have a considerable influence on movement in road traffic and the risks of accidents this entails.

VEHICLE

When considering the vehicle as a factor, the risk to unprotected road users from right-turning trucks primarily derives from the very often insufficient field of vision of the truck driver. The higher sitting position is very beneficial in flowing traffic as the range of vision and the ability to see over other road users enables the driver to drive in an anticipatory manner and to detect danger in good time. It is precisely close up, however, that this advantage turns into a significant disadvantage. The fact that the line of sight is situated higher up means that objects in the immediate vicinity of the vehicle are impossible to detect or only detectable to a degree. This particularly affects pedestrians and cyclists who quickly disappear into the blind spots due to their comparatively small and inconspicuous silhouette, **Fig 12, Fig 13**.

Fig 12: Simulated impact scenario, helmet is just about visible (top); original conditions (below)

The existence of a strip of grass delineates a separation between the motor vehicle traffic and the unprotected road user. Therefore a conflict between the individual truck and the cyclist or pedestrian is restricted to those areas where the used paths cross.

At the same time a correspondingly broad strip of grass also means that the truck driver is only capable of perceiving the cycle and/or foot path next to this strip of grass in the outside right mirror at a greater distance, Fig 14. This means that the standard outside mirror can supply no information on cyclists and pedestrians that are in the immediate vicinity of the intersection. The driver has to rely on the wide-angle mirror. The driver's field of view in this road traffic set-up is further restricted if trees have been planted or, as shown in **Fig 14**, advertising hoardings are located in the field of view.

Fig 13: An example of the right-handed arrangement of mirrors on a truck (top of hair visible)

Fig 14: Advertising hoarding having a detrimental effect on the field of vision

OTHER ROAD USER

A truck is an optimised means of transport for conveying large quantities or heavy loads. These vehicles require not only more space on the road than other road users, but also move differently on account of their dimensions. An articulated lorry cannot turn on a road in the same way as a passenger car. It requires the truck to either swing out to the left beforehand, or to be first of all steered straight ahead before the turning manoeuvre is initiated and to use the entire access funnel. The other road users are often not aware of this necessity and this can lead to misinterpretations of the traffic situation. If the articulated lorry first travels straight ahead, the pedestrian only recognises the turning manoeuvre when the side wall of the trailer is already moving towards him.

TESTS

DEKRA Accident Research has carried out tests on the subject of right-turning trucks at the DEKRA Crash Test Center by simulating the findings garnered in the accident analyses. The programme not only included the simulation of impact scenarios but also investigations into the field of view.

FIELD OF VIEW FROM A TRUCK

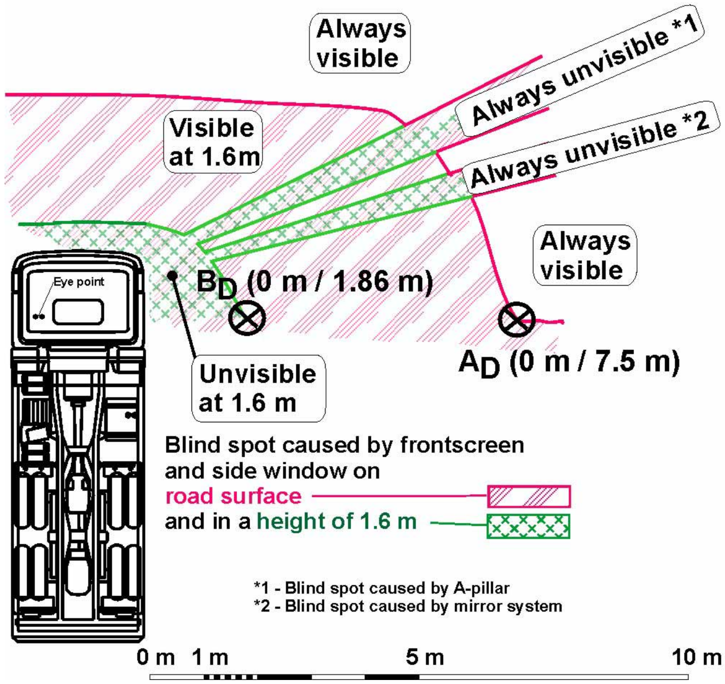
The direct and indirect field of view are the key factors for the situation involving a right-turning truck. This became clear both in the study of the literature as well as during the tests conducted as part of the project and in-depth analyses of road accidents. It is the inadequate field of view forward of the vehicle and to the right in particular that cause the truck drivers considerable problems.

The directive 71/127/EEC /11/ or the successor directive 97/2003/EC /12/ prescribes for the mirrors a field of view of the ground visible to the driver. **Fig 15** and **Fig 16** show the blind spots as a hatched area that exists in a direct view of the ground, cross-hatched for a person 1.75m tall. The height is shown in the illustrations with 1.6 m, so that a part of the head (0.15m) remains visible to the driver. Persons smaller than 1.75 m can only be perceived outside of the cross-hatched area from the driver's position. The indicated points A and B mark the distances in relation to the centre of the outside edge of the right front wheel on the ground. The driver can only perceive a point on the road at a distance of 7.5m on the right next to the vehicle. A point at a height of 1.6m above the road surface must be at least 1.85m away from the driver's cabin (B_D) in order for the driver to see it.

INDIRECT VIEW

Depicting the indirect view is more difficult than the direct view. The incorporation of the field of view regions in photos has proved to be a sensible and also vivid method of depiction. The field of view depicted in the wide-angle mirror can be seen to be arranged far more rearwards on the MB 1748 (**Fig 17**) in comparison to the so-called MIM vehicle (**Fig 18**). A cycle standing at the level of the front axle would be largely visible from the MIM vehicle, whereas it cannot be seen using conventional mirror systems.

A corresponding comparison of the close-proximity mirror (**Fig 19**) with the front mirror (**Fig 20** replacement for the close-proximity mirror) on the MIM vehicle clearly shows the greater coverage of the front mirror. In spite of the improvements the driver needs to get used to the new mirror to be able to allocate the mirror image to the real surrounding. Special note should be made of the objects visible in the border regions of the mirror.



In front of the truck an object on the ground is visible from a distance of 3.1m. An object with a height of 1.6m is visible from a distance of 0.7m in front of the truck. On the right next to the truck the driver can only see the object on the ground at a distance of 7.5m (A_D) away. For a height of 1.6m the minimum distance is 1.86m (B_D) at the height of the right-hand B pillar.

Fig 15: Diagram showing the direct field of view from a Mercedes Benz 1748 (SK-model range)

Apart from the mandatory mirror, the accessories trade offers various mirrors and lenses aimed at improving the indirect view. As part of analysing the field of view, investigations were also undertaken into whether the field of view of the driver can be perceptibly enlarged using a Fresnel lens. To this purpose a standard wide-angle lens was employed that works on the Fresnel principle. It widens the cone of the user's view. One can so-to-speak see around the corner. Conversely, the Fresnel lens reduces the size of the image of the object. It distorts the direct view of the object that, from the vision of the viewer, is behind the lens. However, it does not suffer from the blind spots a mirror has.

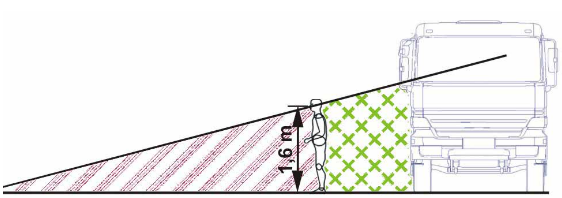


Fig 16: Explanatory picture of the field of view for Fig 15.

Fig 17: Photo showing the indirect field of view from the driver's viewpoint (MB 1748) via the wide-angle mirror (the overlay pyramid stump marks the coverage of the wide-angle mirror; the cycle is located 2.0m away to the truck.)

Fitting the lens close to the rear edge of the side window (**Fig 21**) improves view sidewards and rearwards behind the B pillar of the driver's cabin. The test person was standing outside of the direct field of view and can be easily spotted in the lens. He was located on the ground directly next to the field visible in the starting mirror (see chalk markings). The commencement of the visible field on the ground covered by the lens is documented by the three black marking plates on the ground (five-point targets). Using the lens a point on the ground by the side of the driver's cabin can already be seen at a distance of 2.95 m (A_{L}) (Index L - View through the lens) (Fig 22), while without the lens the background can only be recognised at a distance of 7.5 m (A_D) (Index D - Direct view). For a height of 1.6 m the minimum distance for recognition reduces from 1.86 m (B_D) to 0.6 m (B_L).

Fig 18: Picture showing the indirect field of view from the driver's viewpoint (Mercedes Benz MIM vehicle) via the wide-angle mirror; the marking tape defines the lower limit of coverage in the mirror and the key points of the actual field of view on the ground.

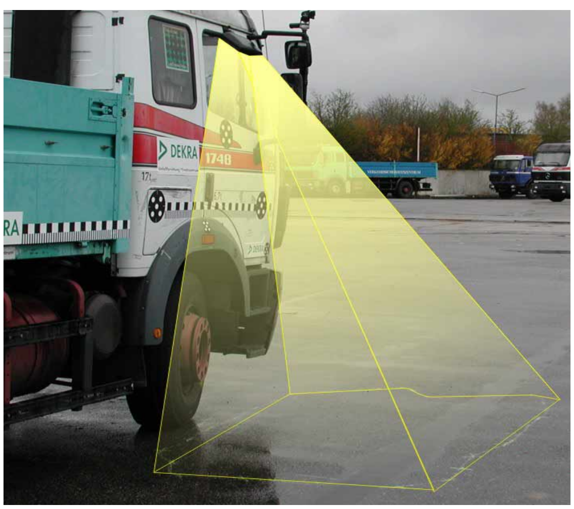


Fig 19: Photo showing the resulting view pyramid from the close-proximity mirror; the line running from the mirror to the marking showing the limitations of the mirror edges (Mercedes Benz 1748) Dynamic tests

The tests simulated impacts to the front right-hand side (No.1) of the corner of the driver's cabin and directly behind the driver's cabin in the area of the side guard (No. 2 - 5, **Fig 23**). The first three tests were impacts involving a moving cyclist; tests 4 and 5 were collisisons with stationary pedestrians. Modified side protection devices were employed in tests 3 and 5.

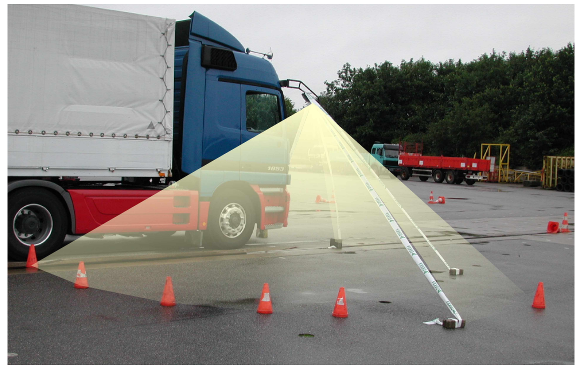


Fig 20: Picture showing the resulting view cone from the front mirror (MB MIM vehicle)

Fig 21: Picture of the indirect field of view (Mercedes Benz 1748) on the front right-hand side upon the fitting of a standard Fresnel lens in the rear part of the right-hand side window, person only visible with Fresnel lens, marking plates define the beginning of the field of view of the Fresnel lens on the ground.

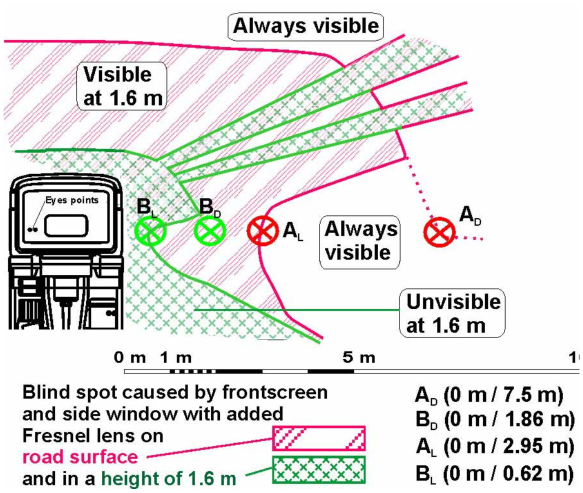


Fig 22: Picture showing the combination of the direct field of view with the addition of the Fresnel lens; position at the rear or the side window

In three further tests the identical driving line as in tests 1 up to 5 was used and the field of view for the truck driver recorded in stages in order to document when the driver sees the future opponent in the mirror. A corner impact (Test 6) and an impact in the region of the side protection system (Test 7) were performed with a conventional mirror system. On the MIM vehicle merely the impact with the corner of the driver's cabin (Test 8) was performed.

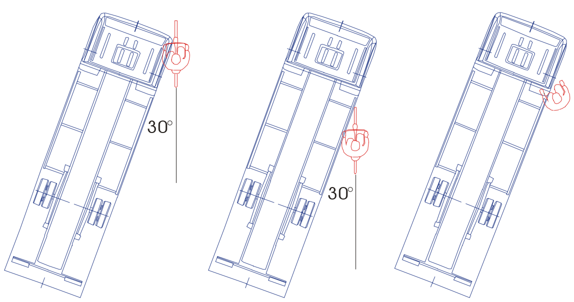


Fig 23: Impact constellation of the tests 1 (left), 2 + 3 (centre), 4 + 5 (right)

In the corner impact involving the MB 1748 (Test 6) the truck driver was unable to see the head of the cyclist until directly before the impact in the side window, **Fig 24** + **Fig 25**. This would in real life be far too late to prevent the accident. In the impact in the side protection area (Test 7) the cyclist could be seen by the truck driver in the wide-angle mirror from the moment the test was run, **Fig 26** + **Fig 27**. The cyclist was so far behind in relation to the truck that he could be spotted in the wide-angle mirror. The cyclist is also visible in the main side mirror directly before the impact. In the corner impact involving the MIM vehicle the cyclist is also always visible in the front mirror and as the test progresses in the wide-angle mirror too (**Fig 28** + **Fig 29**) and then likewise in the side window, **Fig 30**.

The view tests provide a possible explanation for the relative seldom incidence of collisions between cyclists and trucks involving an initial contact in the side protection region (see Fig 11). Mirror systems that have so far been configured in accordance with 71/127/ECC put the truck driver in the position to notice a cyclist at a point in time x when he is towards the rear alongside the truck and to react before the cyclist comes into contact with the side protection system. If the cyclist is at the same point in time somewhat forward alongside the truck and the other conditions are otherwise identical he is not visible or if so only at a very late stage so that a collision in the region of the right-hand corner of the vehicle is probable.

Fig 24: Picture showing the driver's view from the Mercedes Benz 1748 of the (not visible) cyclist for the corner impact scenario , s = 17.1 m before impact, distance of cyclist-truck a = 3.5 m, Test 6

Fig 25: Picture showing the driver's view from the Mercedes Benz 1748 when the cyclist appears for the first time in the field of vision of the driver of the Mercedes Benz 1748, s = 5.9 m before impact, Test 6

Fig 26: Picture showing the driver's view from the Mercedes Benz 1748 of the cyclist in the side impact scenario, s = 16.5 m before impact, Test 7

Fig 27: Picture showing the driver's view from the Mercedes Benz 1748 of the cyclist for the side impact scenario, impact scenario Test 7

Fig 28: Picture showing the driver's view from the Mercedes Benz MIM vehicle of the cyclist in the corner impact scenario, s = 18.5 m before impact, Test 8

Fig 29: Picture showing the driver's view from the Mercedes Benz MIM vehicle of the cyclist in the corner impact scenario, impact scenario, Test 8

Fig 30: Picture showing the driver's view from the Mercedes Benz MIM vehicle when the cyclist appears in the direct field of view of the driver of the Mercedes Benz 1748 for the first time, s = 5.9 m before impact, Test 8

ATTEMPTS TO FIND TECHNICAL SOLUTIONS

OPTICAL SYSTEMS

Basically, the truck driver should have a direct field of view that is as good as possible. This means in detail that the vehicle should have large front and side windows that extend down as low as possible. The mirrors prescribed by the existing 71/127/ECC display clear gaps in assuring indirect view for the truck driver in particular as regards turning right as was shown in the accident analysis and the tests.

In comparison to the currently existing regulations the new mirror directive 2003/97/EC /12/ contains considerable improvements in the prescribed field of view. Apart from extending the field of view for the main outside mirror (Group 3) and the wide-angle mirror (Group 4) the new directive also prescribes a field of view in front of the truck, **Fig 31**. These new stipulations appear at first sight to be only possible by adding at least a further mirror or camera system. The new mirror system of the MIM vehicle, altering the arrangement as well as using modified mirrors, enables the directive to be fulfilled by using three mirrors, **Fig 32**. This type of fitting is not new. It has recently become customary on coaches and this type of mirror visible through the front screen has been fitted as standard on trucks for some time now.

The mirror system fitted to the MIM vehicle more or less exhausts possible further development as far as the truck mirror is concerned. The mirror system represents the furthest development can go and additional improvements can no longer be expected here. One of the serious weak points of indirect view via mirrors is the compelling need to match it to the direct field of view of the driver. The driver must be able to see the mirror himself. This necessity does not apply to camera monitor systems as well as for sensor-based assistance systems.

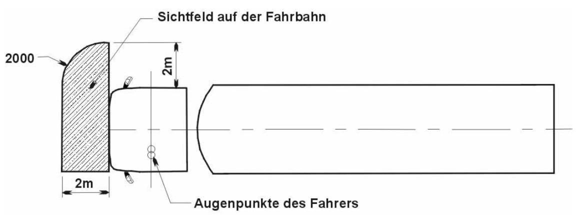


Fig 31: Field of view of the front mirror (Group VI) as foreseen by 2003/97/ECC

Fig 32: Field of view via the wing mirror in the DaimlerChrysler MIM vehicle /2/

The employment of supplemental systems to improve the indirect field of view such as additional mirrors, lenses or camera monitor systems are to be considered critically as regards use and the expected distraction of the driver occasioned by consulting the systems and processing the information. The increased deployment of camera monitor systems requires more intensive research work to be done. One of the questions yet to be answered is that of determining the most optimum position of the monitor.

DRIVER ASSISTANCE SYSTEMS

In contrast to the passive mirror and camera monitor systems mentioned so far, assistance systems function actively. The assistance systems are geared to special situations categorised as representing a problem in road traffic such as, for example, changing lane. The system lends the driver support and thus relieves him of some of his work in performing his task as driver. The assistance systems possess various levels of automation/15/. In the simplest version they inform the driver merely about an existing situation. A fully automated assistance system performs an action independently without the driver being able to intervene.

In comparison to the field of view based around the driver, the detection range of assistance systems is to be defined completely differently. The detection range is to be understood as the spatial area, also called the ROI ("Region Of Interest", /14/), that the assistance system sensors are to monitor. The detection range can be precisely delimited on sensor systems. A possible parameter for the turning manoeuvre situation could be a monitoring function that focuses on the right, alongside and front next to the vehicle spanning a range of up to 5 m to the outer contours of the vehicle.

Assistance systems are the way ahead. Currently under development are turning assistance research projects such as the version developed as part of the EU Project PROTECTOR, Fig 33.

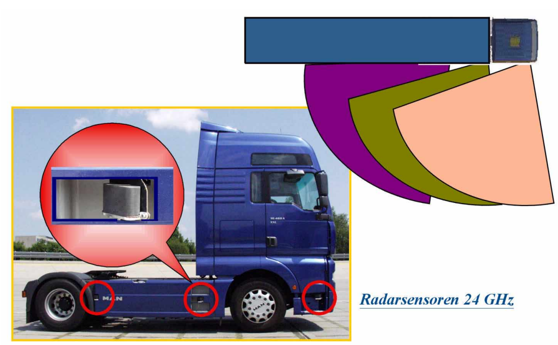


Fig 33: Arrangement and range of sensors on the Demonstrator with turning assistant developed as part of the EU Project PROTECTOR (Source: MAN)

ENVIRONMENT RELATED MEASURES

The structural design of the environment, e.g. in intersections, can influence the incidence of accidents. This also applies to vehicle-turning accidents. Structural measures must, however, be based on the local conditions. Requirements can only be implemented insofar as they are technically feasible. In densely built-up urban environments it is partially unrealistic and consequently not always practicable to implement requirements for generously apportioned intersections. Existing buildings including the front pedestrian paths restrict the options of traffic planers and building authorities.

Well-designed building measures that take into account existing restrictions can be seen in **Fig 34** . Here the stop line for cyclists is about 3 m closer to the traffic lights than for trucks. This means the cyclist is situated in the field of view of any truck driver who would like to turn right there. In addition, the lights turn green for the cyclists before they do so for motor vehicles. This allows the cyclist to start off earlier, to remain in the field of vision of the truck driver and not to end up in the blind spot. The distance of the stop lines should be at least 3 m. Any less than this would mean that the cyclist can still end up in the blind spot in unfavourable circumstances.

Fig 34: Design of the traffic flow system and the traffic light staggering system in favour of cyclists

SAFETY CONCEPT

The findings garnered from the accident analysis create a completely different view on actual accident situation as expected. The impact of the unprotected road user takes place primarily around the front right-hand side of the vehicle corner. A noteworthy percentage of cyclists/pedestrians end up under the vehicle well in front of the front axle. A round table of experts examined and discussed a catalogue of possible measures to reduce or eliminate problems created by a right-turning truck. The safety concept measures also incorporate the aspects discussed during the meeting of experts.

The diverse measures affect drivers, driving schools, law givers, manufacturers, media, administrative districts, municipalities, police, schools, haulage companies, road building authorities, technical monitoring organisations and associations. They are subdivided into when they can be implemented, when they can become effective and effectiveness on the accident as well as on individual vehicle groups.

The visibility problems in the situation “a right-turning truck is in conflict with a cyclist or pedestrian” show additionally a shortcoming of information of the other road users. This shortcoming includes the possibilities of visibility and movement of a truck. There are urgent needs for campaigns to elucidate all classes of population. It is not surprising that children are not aware of all the details pertaining to trucks. It is, however, remarkable that more than a few judges that preside over the misconduct of truck drivers do not know what the view from the inside of a truck looks like. This shows that every Euro invested in a corresponding instructional campaign is money well spent. Schools could integrate relative examples into their teaching. But adults, too, must be included in this instructional work. Accompanying campaigns and events can employ printed mater or suitable media for downloading in the internet or graphic video material. Real life exercises in and on the truck have much to recommend them.

The additional measures concern among other things improved mirror systems, a low bottom line of the windscreen and side window, development and adoption of driver assistance systems, optimised configuration of the signposting and the run of the road, change of the German road traffic regulations (§ 5 para. 8: a bicyclist is allowed to pass a standing truck on the right side) and also the training of the truck drivers.

SUMMARY AND OUTLOOK

Over the course of research projects, in the literature as well as in the public the problem of the situation of "a right-turning truck and the conflict with a cyclist or pedestrian“ has been discussed since the late seventies.

The in-depth accident analyses led to new findings as regards the initial contact between the truck and the unprotected road user. More than half of the cyclists and pedestrians came into initial contact around the right front of the vehicle corner. This and the resulting frequently run over by the front axle require efforts to be concentrated on the front right-hand corner. The battery of tests conducted at the DEKRA Crash Center covered both impact situations around the truck side protection area as well as the corner impact on the truck.

The literature evaluated as part of the project sees the direct and indirect field of view as the key factors for the situation involving a right-turning truck. One of the well-known reasons for the problems facing the truck driver in this situation is the insufficient view to the right and in front. A basic change is to take place in this area with the advent of the new directive 2003/97/EC.

In addition to the IRR figures, a total of 90 accidents were available for in-depth accident analyses in which a right-turning truck collided with a cyclist or pedestrian.

- The initial contact takes place in the majority of cases (57%) in the region of the front right-hand vehicle corner. This includes the front right-hand part of the vehicle, the right-hand vehicle corner and the right-hand region back to the front axle.
- Half (50%) of the unprotected road users end up in front of the front right-hand wheel or in the region around the right front wheel under the truck.
- Construction and municipal vehicles are exceedingly often involved in turning accidents.

There are basically two turning scenarios, both with their inherently different problems.

Scenario 1: The truck drives up to the turn off and turns right at a correspondingly reduced speed. During the turning manoeuvre both the truck and the cycle have a similar rate of speed. A cyclist located in the truck driver’s blind spot during the turning manoeuvre remains hidden therein until shortly before the collision takes place.

Scenario 2: The truck stopped before the turning manoeuvre. This stop can be caused by traffic conditions or be due to a traffic light installation. It includes the 10% of the accidents in which the cyclist is in the same lane and intending to cycle past on the right of the stationary truck.

The investigations in the field of view comprised measurements of the direct and indirect field of view of a truck using a mirror system conforming to the current regulation (71/127/ECC) and with the addition of a field of vision aid in the form of a Fresnel lens. As a comparison, the same field of view measurements were conducted on the Daimler-Chrysler MIM vehicle.

A particularly problematical view situation exists at the pre-cash stage when the cyclist contacts the area of the front right vehicle corner. In a collision in the area of the side protection the truck driver driving a truck as currently found on the road in combination with the prescribed mirrors is always able to see the cyclist before the collision. This is not the case with an impact around the area of the front vehicle corner. This explains the more frequently encountered impact situation at the driver’s cabin corner in the accident analyses.

When turning right that part of the field of view that constitutes a particular problem for the truck driver is that directly to the right next to the driver’s cabin, extending to about 3 m in front of the truck. The truck driver has virtually no field of view into this zone with the previously described systems. Consequently he finds it impossible to detect any pedestrian and cyclists located there. A corresponding improvement of the field of view is urgently required. Put generally, the driver requires further information about objects located in this area.

It is precisely the investigation of the traffic situation involving “right-turning trucks coming into conflict with a cyclists or pedestrian” that reveals not only the field of view problem of the truck driver but also a considerable lack of information possessed by other road users about the viewing possibilities and the manoeuvrability behaviour of a truck. Here, instructional work aimed at the public at large is urgently required.

In the future we can expect that the introduction of different improvements will change the road traffic situation. Targeted information campaigns will bear fruit and pedestrians and cyclists will be in a position to correctly read the truck driver’s manoeuvring intentions. The truck driver will encounter a host of changes. In those areas where a large blind spot still leaves uncertainty the truck driver will in future have more information about whether another road user is located there. Indeed the advent of information and assistance systems among other things can also change the behaviour of the truck driver and the cyclist or pedestrian. The ergonomic, occupational physiological and psychological effects on the road user that this brings with it still require further interdisciplinary research. Here, in the run-up to the market launch of new systems, an attempt should be made to assess the possible effects in order to sound out the existing optimising potential and to be able to counter the negative consequences early enough. It is absolutely essential that the market launch of new types of systems be accompanied by the gathering and evaluation of relevant accident scenarios in order to record the actual changes made on real accidents and to analyse deviations to the predictions.

The MIM vehicle developed by DaimlerChrysler shows a project study with its optimised mirror configuration and positioning shows what can be achieved here. The attainable improvements in the indirect field of view have been remarkable and if systematically introduced on all trucks would not only reduce accident figures for the situation involving a right-turning vehicle. The research study developed by MAN, which incorporates turning assistants, points the way ahead in electronic driver aids. A system that warns the driver when a corresponding danger is detected is already the current state of technology. In future, a system is also conceivable that actively intervenes in a correspondingly diagnosed situation.

Further research is required into the effect of new or modified systems on the driver. It must take account of the ergonomic, occupational-physiological and psychological aspects.

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DEVELOPMENT OF SAFETY CONCEPT TRUCKS; ASV CONCEPT L AND ASV CONCEPT C

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ABSTRACT

To realize a dream of “zero-nize” the fatalities and injuries in traffic accidents, or even accidents themselves, related to commercial vehicles, future concepts for both large truck and small delivery truck, with a name ASV concept L (long haul truck), and ASV concept C (city use) were studied.

The newest available traffic accident statistics data in Japan was used for analyses to know the characteristics of accidents each types of commercial vehicles are involved. The result showed the accidents related to large trucks and one related to small trucks are quite different. Among the accidents related to large trucks used mainly for long haul use, which consist 15% of all fatalities, almost 50% of the fatalities are car occupants. For the small trucks used mainly in city for delivery purpose, almost 40% of the accidents are with pedestrians and cyclists.

From these analyses, it was concluded that the following three areas are the most important areas to tackle with.

1 .Frontal collision between car and large trucks
2. Rear-end collision of large trucks
3. Small truck accidents of pedestrians and cyclists at intersections

In ASV concept L, Energy Absorbing Front Structure was proposed to reduce a damage of car occupants and 50% decrease in fatalities in such accidents may be possible with the structure. Pre-crash Safety System is to cope with rear-end collision. With millimeter-wave length radar, objects are found and the system gives warning to the driver. In case driver takes no avoiding maneuver, the system automatically applies brake to reduce the impact speed.

In ASV concept C, Body Structure for Pedestrian Safety was proposed. Blind-spot Monitoring System for vehicle front, rear and below to assist the driver, Ultra-thin Pillar for better frontal view and Pedestrian Detection and Warning System were proposed.

INTRODUCTION

Fatalities in traffic accidents in Japan have been decreasing for this 10 years and it came to the number 7,358 in 2004. On the other hand, injuries and number of accidents have been increasing. This trend is also true for the accidents which involved commercial vehicles, i.e. large trucks, medium trucks and small trucks (See Figure 1). Reduction of traffic accidents and their casualties is worldwide target and Japan is one of the countries which have tackled to achieve the target. In January 2003, Japanese prime minister announced his vision of halving the fatalities in traffic accident in ten years, and various measures are now under way. Final target is to “zero-nize” the accidents, or realization of accident free society. To reach this final target, there must be some big jumps which are something different from current measures.

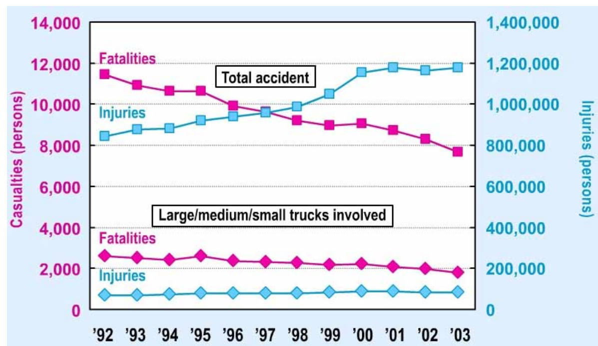

Figure 1. Changes of casualties in traffic accidents.

VISION ON SAFETY IMPROVEMENT

Hino Motors, Ltd., a commercial vehicle manufacturer in Japan holds a vision of achieving the zero casualties in accidents which involve commercial vehicles (See Figure 2). Here, to realize this vision, safety concepts; both for large truck and small truck were studied.

Figure 2. Vision on safety improvement.

ANALYSIS OF COMMERCIAL VEHICLE ACCIDENTS

Using the most recent available accident statistic data in Japan, traffic accidents which involved commercial vehicles were analyzed for each truck category. Here, the large truck is with the GVW of more than 8 tons, medium truck is with the GVW of 7 tons to 8 tons, and small truck is with the GVW of less than 7 tons.

Result shows that the contents or types of accidents differ from category to category because of the difference in use; large trucks are mainly used on highways and trunk routes, small trucks are mainly used for delivery purpose, and medium trucks are just between these two (See Figure 3).

In accidents involved large trucks, which make up 13% of all traffic accident fatalities and 53 % of all fatalities related to commercial vehicles, passenger car occupants hold the largest shear and it is almost 50 %. This leads to the fact that the first priority in the safety of large truck shall be given to the accidents with passenger cars. Type of accident most frequently happen in passenger car to truck accident is frontal collision. From the analysis, 90 % of these frontal collisions occur as a result of departing lanes of passenger cars. In frontal collisions higher relative speed easily result in fatal accidents. Next there comes the rear-end collision. The rear-end collision, especially the high speed accidents on the highways, can result in fatal accidents for passenger car occupants.

In accidents involved small trucks, which make up 5 % of all traffic accident fatalities and 22 % of all fatalities related to commercial vehicles, pedestrians and cyclists hold the largest shear and should be given the first priority. In pedestrian accidents, accidents on intersection in daylight time are most common, and accidents at right turn maneuver are most frequent. (Japan is in left-hand traffic, and the right turn means the turn across the opposite traffic lane.)

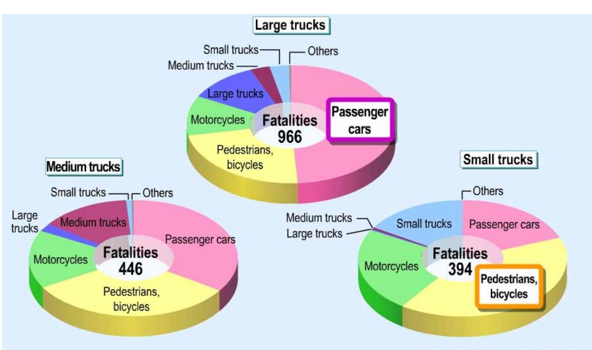

Figure 3. Fatal accidents which involve commercial vehicles.

STUDY ON SAFETY CONCEPT

Based on the result of accident data analysis, safety concepts both for large truck and small truck were studied. Basic idea was as follows. To operate the vehicle safely, it is most important that the vehicle is easy to operate for every person; for male and female, for young and elderly person. So, for the basis of safety concept trucks, "Universal Design" concept was applied for the cab interior and driving devices. Upon this base, appropriate safety systems both in active safety and in passive safety were built up (See Figure 4).

In active safety, assist of driver's recognition and judgment, using intelligent traffic system technology was studied. "No blind spots around the vehicle" is the main concept in this facet (See Figure 5).

In passive safety, "compatibility" was studied. In passenger car in general, compatibility is the idea to keep equivalent safety level for both cars in case of collision between small-size car and large-size car. Compatibility in commercial vehicles is a little different. In the case of large truck, it is the matter between passenger car and large truck and the compatibility is to reduce the risk of passenger car occupants in case of collision. In the case of small truck, it is the matter between pedestrian and small truck. And the compatibility is to reduce the damage of pedestrian in case of pedestrian accidents.

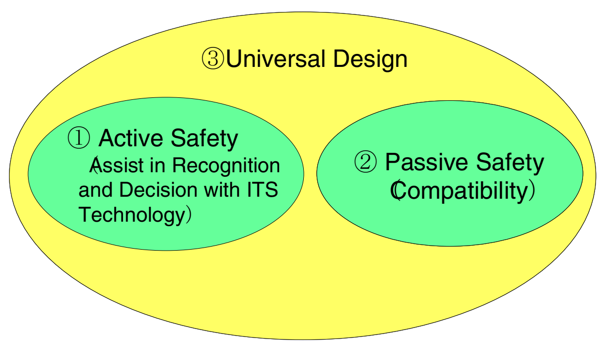

Figure 4. Safety concept of future trucks.

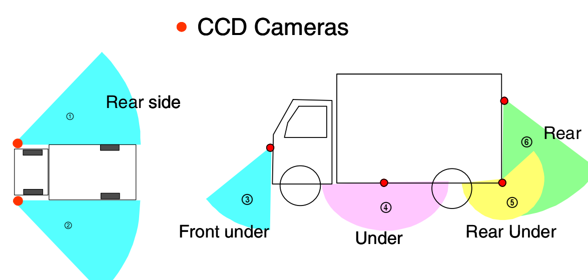

Figure 5. No blind spot around the vehicle.

Safety Concept of Large Truck: ASV concept L

In the study of safety concept of large truck: ASV concept L, area of the study was focused on long-haul, cargo truck. Protection of passenger car occupants in case of frontal collision, mitigation of damage in case of rear-end collision and support of visibility in highway cruising are main topics. Systems included in the concept are introduced in the following (See Figure 6).

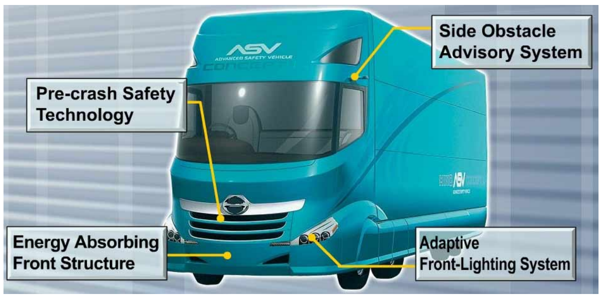

Figure 6. ASV concept L.

Energy Absorbing Front Structure

ASV concept L has energy absorbing front structure which aims at the reduction of impact and damage to the passenger car in case of frontal collision (See Figure 7). This energy absorbing front structure has two functions. One is to absorb crash energy of passenger car, and another is to put the opposing car aside in offset collision case which is most common in the frontal collision. This can reduce the damage which can be expected in subsequent events in the accident (See Figure 8). In our estimation, this structure has potential to cope with frontal collision up to 90 km/h and saves the 50 % of fatalities in the type of accidents, compare to the 15 % with front under-run protection device in ECE regulation (See Figure 9). To put this structure into practice in the long-haul truck, relaxation of the restrictions on total vehicle length shall be discussed. Our study showed that 500 mm crash stroke is necessary to provide sufficient effectiveness. This is basically to reduce, not the damage of the truck driver, but damage of opposing car occupants, and to make the technology become widely used, load capacity shall not be reduced from the one current trucks have. Discussion among the users, legislative, and manufacturers is necessary.

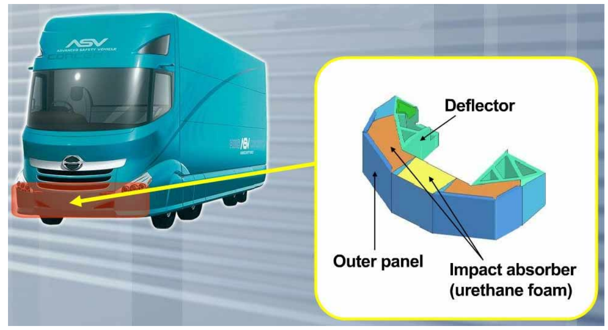

Figure 7. Energy absorbing front structure.

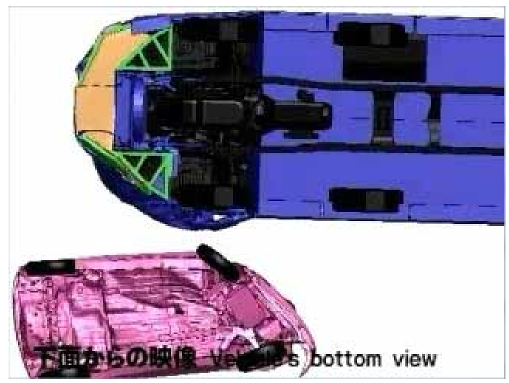

Figure 8. Simulation result.

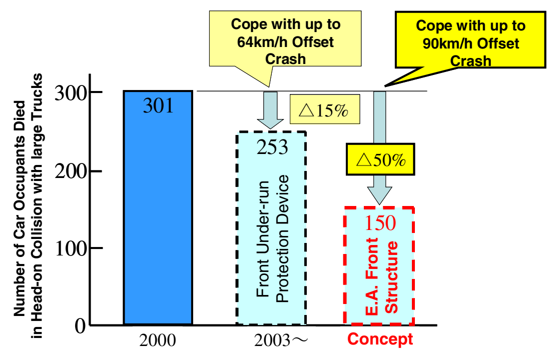

Figure 9. Estimation of reduction in fatalities.

Pre-crash Safety Technology

To reduce the fatalities in rear-end collision of large trucks, the pre-crash safety technology was proposed. Millimeter wave radar detects obstacle ahead and if there is any possibility of collision, gives warning to the driver. If driver does not take any avoiding maneuver, the system automatically applies brake force and reduces the impact speed and thus mitigates the damage to the obstacle (See Figure 10).

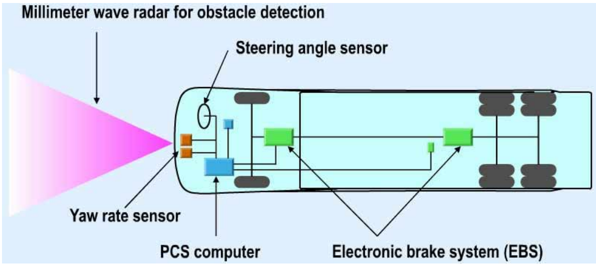

Figure 10. Pre-crash safety system.

<u>**Adaptive Front-lighting System (AFS)**</u>

Adaptive front-lighting system (AFS) aims to offer drivers better view compared to the traditional head-light system, in case of driving curve or turning an intersection at night. The proposed system has a function to direct the main head-light beam to the direction where the vehicle will be, according to the steering angle. In addition, based on the maneuver of large truck at an intersection, additional sideward lamp is turned on when the vehicle makes turning with certain low speed and with turning lamp activated (See Figure 11, 12, 13).

Figure 11. Adaptive front-lighting system (AFS).

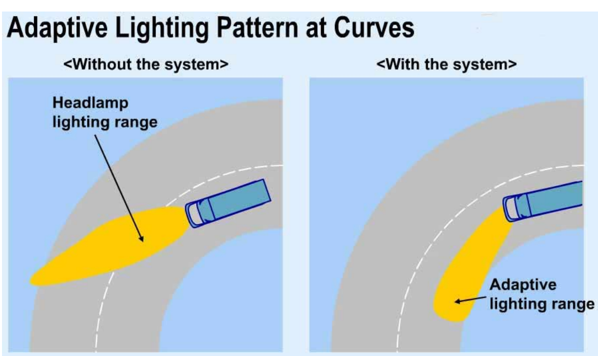

Figure 12. Function of AFS at curves.

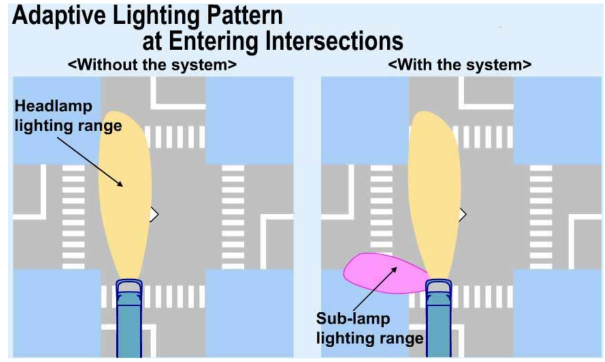

Figure 13. Function of AFS at intersections.

<u>**Side Obstacle Advisory System**</u>

Side obstacle advisory system informs presence of vehicles on adjacent lane when driver intends to make a lane change. ASV concept L is equipped with cameras on the right and left of the cabin instead of current mirrors. By analyzing the view of the cameras, only the objects which are approaching to the vehicle on adjacent lane are detected and the system gives warning to the driver (See Figure 14, 15).

Figure 14. Side obstacle advisory system; cameras.

Figure 15. Detection of objects.

Safety Concept of Small Truck: ASV concept C

In the study of safety concept of small truck: ASV concept C, area of the study was focused on delivery truck mainly used in urban area. Protection of pedestrians in case of pedestrian accidents is the main topic. Systems included in the concept are introduced in the following (See Figure 16).

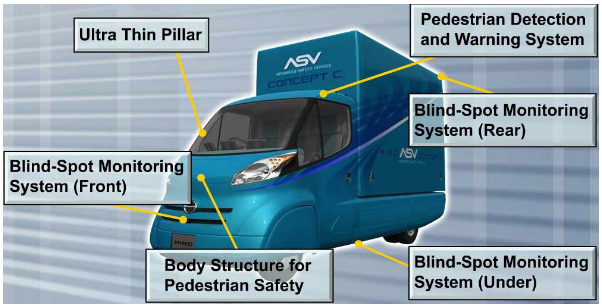

Figure 16. ASV concept C.

<u>Ultra Thin Pillar</u>

Ultra thin pillar is to improve the visibility of pedestrians and cyclist in the right and left turning maneuver. When the section of the pillar is thinner compared to the width of right and left eyes of the driver, objects behind the pillar do not hide behind the pillar because of the parallax of right and left eyes (See Figure 17, 18).

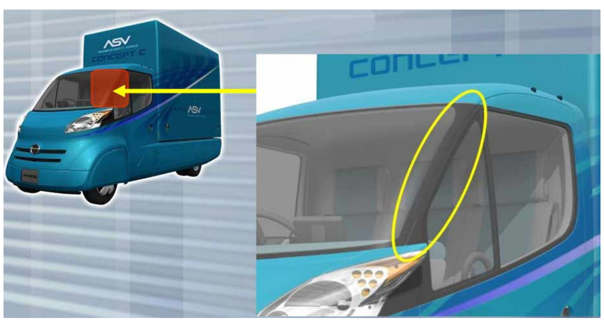

Figure 17. Ultra thin pillar.

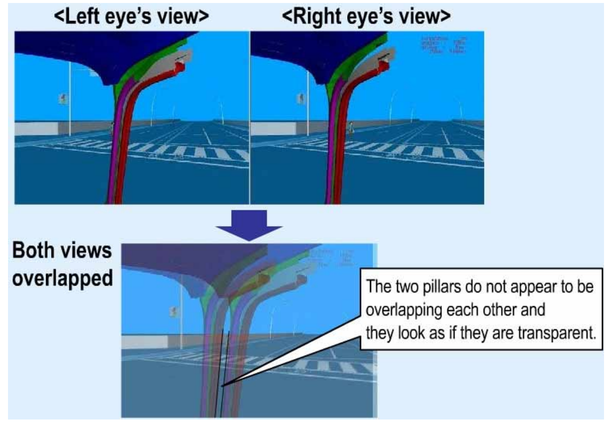

Figure 18. Function of ultra thin pillar.

<u>Pedestrian Detection and Warning System</u>

Pedestrian detection and warning system detects pedestrians in the right and left turning maneuver and warns the driver when there are pedestrians. Stereo cameras on both right and left side of roof take images of side-rear of the vehicle. From the image data processing, only pedestrians are extracted and the direction and movement of the pedestrians are analyzed. If there is possibility of contact between pedestrians and the vehicle, the system warns the driver with sound alarm (See Figure 19, 20).

Figure 19. Pedestrian detection and warning system; stereo cameras.

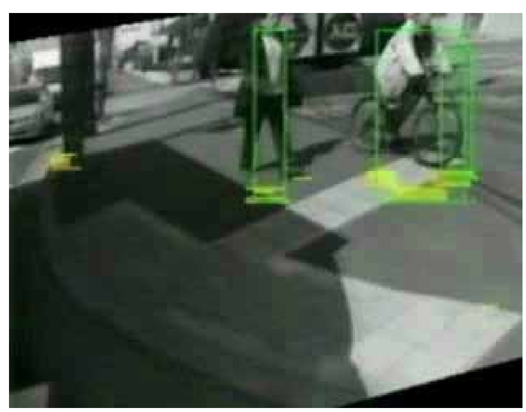

Figure 20. Detection of pedestrians.

Blind Spot Monitoring System (Front, Rear and Under the vehicle)

To realize the concept of "No Blind Spot around the Vehicle", Cameras are used to support the driver's visibility and to detect objects and warn the driver. Wide angle camera on the front of vehicle is effective when the vehicle going out from narrow alley surrounded by walls. With the image data processing, system detects objects approaching the vehicle from left side and right side and warns driver (See Figure 21, 22). Wide angle camera on the rear-end of the vehicle provides the view on the back of vehicle where drivers usually have difficulty to confirm the safety, and if there are any moving objects system gives warning to the driver (See Figure 23, 24). Wide angle camera on the bottom of the vehicle takes the first photograph when driver stops the vehicle and removes the key. When driver returns to the vehicle and inserts the key again, the camera takes the second photograph. If there is any difference between the first and the second photograph, the system warns the driver of the possibility that something entered beneath the vehicle. It is also possible to disable the engine start (See Figure 25, 26).

Figure 21. Blind spot monitoring system; front camera.

Figure 22. Detection of objects by front camera.

Figure 23. Blind spot monitoring system; rear camera.

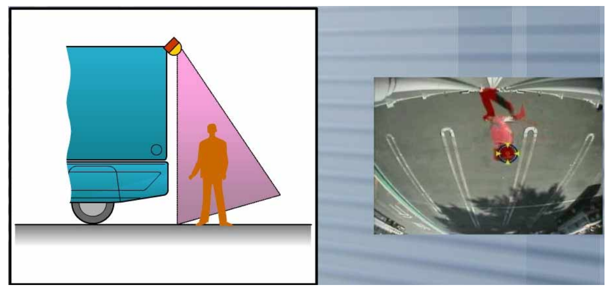

Figure 24. Detection of objects by rear camera.

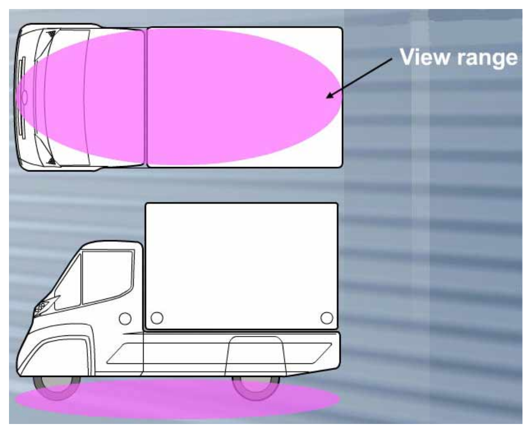

Figure 25. Blind spot monitoring system; bottom camera.

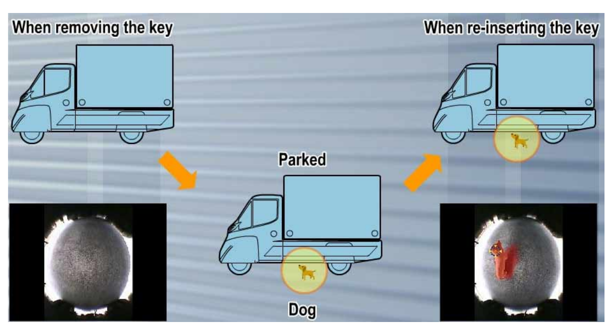

Figure 26. Detection of objects by bottom camera.

<u>**Body Structure for Pedestrian Safety**</u>

The rare event of collision with pedestrians, the bonnet structure with high impact absorbing capacity protects the pedestrian's head (See Figure 27).

Figure 27. Body structure for pedestrian safety; head impact test.

CONCLUSION

Based on the analysis of most recent traffic accident statistic data, safety concepts of both large truck and small truck which aim at the realization of "zero traffic accident" are studied. In large truck, protection of passenger cars, and in small truck, protection of pedestrians is the first priority. To realize the "accident free society" it is necessary to expand the ideas beyond the limit of current vehicles. The shape of the future truck may have different shape from the current one. The system proposed here in the concepts will be realized one by one. Discussion with people from wide area; users, legislatives, manufacturers is most welcomed.

ANALYSIS OF ACCIDENTS INVOLVING LIGHT COMMERCIAL VEHICLES IN THE UK

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Iain Knight
TRL Ltd
United Kingdom
Paper Number 05-0315

ABSTRACT

In 2002, light commercial vehicles (LCV) with a gross vehicle weight (GVW) less than 3500kg accounted for 11.3% of motorised road traffic (in terms of billion vehicle kilometres travelled) in the UK, a steady increase from 10.0% in 1992.

The UK Department for Transport (DfT) commissioned TRL to carry out the Heavy Vehicle Crash Injury Study (HVCIS), which is a multi-disciplinary study into heavy vehicle safety. One part of this project is research into fatal accidents involving LCVs, in order to determine the causes of LCV accidents and to begin to identify cost-effective countermeasures that could improve safety for accidents involving this type of vehicle.

Between 1995 and 1998, there were a total of 1,221 fatal accidents involving LCVs recorded in the UK. TRL obtained and analysed the police accident reports for 43% of these fatal accidents. Data taken from the police reports for analysis included loading details, load movement, vehicle condition, journey purpose and accident causation. Impact details were also coded, using a modified form of the SAE Collision Deformation Classification system.

The report presents the analysis of the data from the completed LCV part of the Heavy Vehicle Crash Injury Study and investigates the types of accident involving these classes of vehicle and the road users at most risk of injury. Factors such as vehicle defects and driver behaviour are also reviewed. Suggestions are made where changes in vehicle design could have the potential to reduce the number and/or severity of LCV accidents and associated injury risk, including both primary and secondary aspects.

INTRODUCTION

There is anecdotal evidence to suggest that there has been an increase in the use of LCVs possibly because of increased home delivery and internet shopping. National transport statistics show that in 1993, LCVs accounted for 10.1% of the road traffic in the UK. By 2003, this had steadily increased to 11.8% [1]. LCV traffic increased by 39% in comparison with a 19% increase in all traffic [1].

The aim of this paper is to analyse the involvement of LCVs in accidents and identify possible cost effective countermeasures that can be implemented to reduce the number of casualties resulting from LCV accidents. The trends for accidents involving LCVs are introduced and an analysis of fatal accidents is described. Potential countermeasures to avoid and reduce the severity of accidents are discussed.

It should be noted that the views expressed in this paper are the views of the authors and not necessarily those of the UK Department for Transport.

ACCIDENT TRENDS 1993-2003

Data from the UK national road accident database (STATS19) has been obtained and analysed for accidents that occurred between 1993 and 2003 inclusive. The analysis considered accidents that involved at least one LCV. The accident sample contained data relating to 196,128 accidents involving 419,879 vehicles and 275,829 casualties.

Figure 1 shows how the accident rate for all vehicles and LCVs has changed during the ten year period 1993 to 2003.

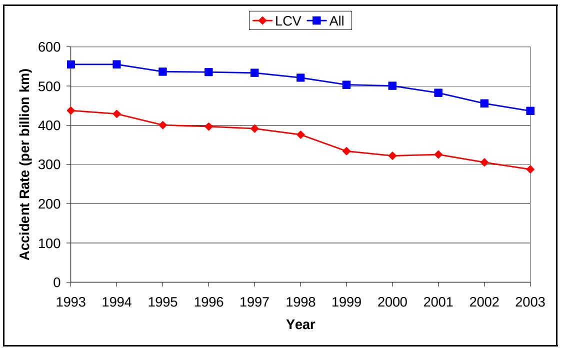

Figure 1. **Trend in accident rate for all accidents and those involving LCVs, 1993-2003 (STATS19)**.

Figure 1 shows that there has been approximately a 43% reduction in the accident rate for accidents involving LCVs between 1993 and 2003. Over the same period, the accident rate for all vehicles has reduced by 21%.

Figure 2 shows the trends in casualty rates for fatal and killed or seriously injured (KSI) road users for accidents involving LCVs. The data for all road casualties are shown for comparison.

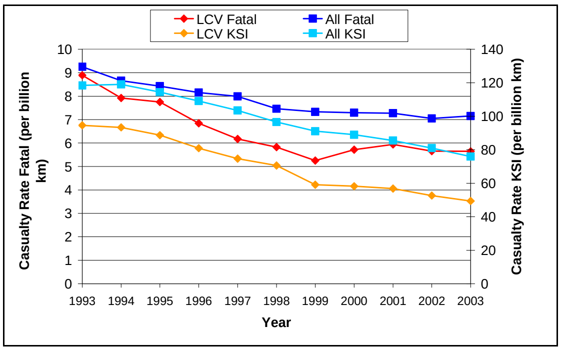

Figure 2. Fatal and KSI casualty rates for all road users and those injured in accidents with LCVs, 1993-2003 (STATS19)

Figure 2 shows that the casualty rates have reduced for both fatal and KSI casualties in all accidents by 23% and 36% respectively. For casualties caused in accidents involving LCVs, the casualty rates have also reduced. The fatality rate reduced by 37% and the KSI rate reduced by 48% over the 10 year period. However, since 1999 the fatality rate for accidents involving LCVs has risen or stayed constant contrary to other trends.

During the period 1993 to 2003, LCVs were involved in an average of 7.7% of all accidents. However, an average of 9% of all fatalities resulted from accidents involving an LCV. This data shows that although the LCV accident rate has decreased more than for accidents involving all vehicle types, LCVs are involved in a higher proportion of fatal accidents than average.

Figure 3 shows the percentage of vehicle types that were involved in accidents of all severities with LCVs.

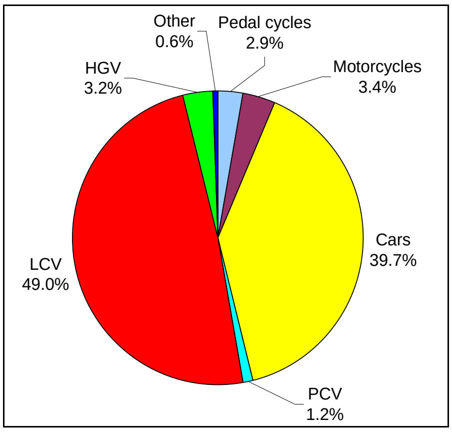

Figure 3. Percentage of each vehicle type involved in LCV accidents (STATS19)

The most frequent type of vehicle involved in these accidents are LCVs, 49%. This is to be expected because at least one LCV has to be involved in the accident for it to be considered in the analysis. The LCV involvement is less than 50% because some accidents will involve multiple opponent vehicles. The second most frequent type of vehicle involved in accidents with LCVs are cars, almost 40%. There are significantly more cars involved than other types of vehicle, excluding LCVs. This is probably because cars comprise 80% of the vehicle fleet [1] and therefore the chance of the collision partner being a car is high.

Figure 4 shows the percentage of each vehicle type that are involved in LCV accidents that result in a fatality.

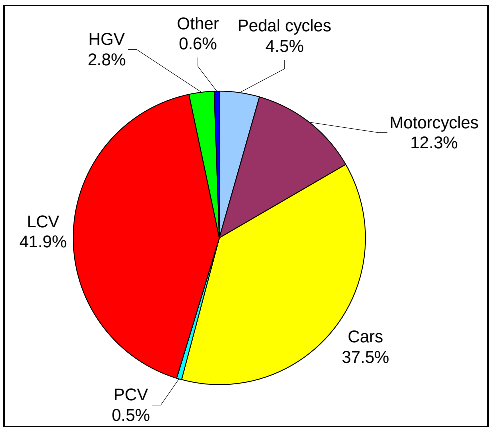

Figure 4. Percentage of each vehicle type involved in fatal LCV accidents (STATS19)

The most significant difference between the vehicles involved in accidents of all severities and those involved in fatal accidents is the number of motorcycles involved. When only fatal accidents are considered, motorcycles account for over 12% of the vehicles involved, whereas they account for less than 4% of vehicles involved in accidents of all severities. Motorcycles are over-represented in fatal accidents, which may be because of the vulnerability of the motorcyclists.

There were a total of 275,829 casualties, 3,497 of which were fatal and 34,279 serious. The distribution of road users casualties are shown in Figure 5.

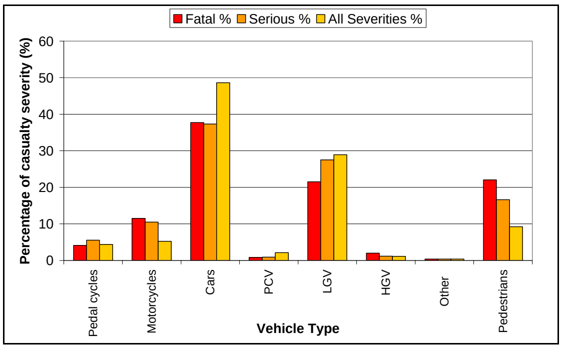

Figure 5. Distribution of road user casualties by severity

The most frequently injured road users in accidents involving LCVs are car occupants (49%) followed by LCV occupants (29%) and pedestrians (9%). Car occupants are also the most frequently killed road users, accounting for 38% of the fatalities.

Pedestrians and LCV occupants are the second and third most frequent road user killed, accounting for 22% and 21.5% of the fatalities, respectively. The proportion of motorcyclists, car occupants, HGV occupants and pedestrians that are fatally injured is higher than those that are seriously injured. Vulnerable road users, particularly pedestrians and motorcyclists are at a proportionately greater risk of serious or fatal injury when compared with all severities. This observation relates to their lower level of protection compared with other road users.

ANALYSIS OF FATAL ACCIDENT DATA

The HVCIS fatals database contains data from accidents involving LCVs, heavy goods vehicles (HGVs), passenger carrying vehicles (PCVs) and vehicles classed as "Other Motor Vehicles" (OMVs).Early population of the database was focused on LCV accidents and contains 27% of the fatalities in STATS19 for that period resulting from LCV accidents. Later releases of the database only include LCVs that are involved in accidents with the other types of vehicle which are of interest (HGVs, PCVs etc.) and so the data for LCVs may be skewed to accidents with larger vehicles. This analysis has been carried out on the first release (phase 1a) of the database to minimise this sampling bias.

Assessment of countermeasures and emerging technologies

For each accident studied, a judgement was made as to whether any modifications to the design of the LCV might have enabled it to avoid the collision or reduce the severity of injuries to non-fatal. In making this judgement many factors had to be taken into consideration including closing speed, road surface conditions, available space for avoiding action, seatbelt use, as well as the age and health of fatality. The nature of this judgement can be rather subjective, therefore a probability scale was used with each countermeasure being marked as "quite likely", "probably", or "maybe" avoiding the accident. To determine an estimate of the benefits of the countermeasures that have been identified non statistical probabilities were assigned to each countermeasure. These were 1.0 to the "quite likelies", 0.75 to the "probables", and 0.25 to the "maybes" to produce a subjective best estimate of the likely benefits.

The countermeasures that are assessed include a number of emerging and recently developed technologies that might, if they work, prevent or reduce the severity of some types of accident and subsequently injury. These technologies include collision avoidance, lane following and ABS.

Making the assumption that these new technologies can be made to work reliably, TRL has reviewed the accident cases and attempted to predict the savings that might be achieved by using them. In some cases theoretical systems are considered with specific information about how they work. Examples of when such technologies should be coded are:

- Where an LCV driver suffers a lack of attention or falls asleep and fails to notice slow moving or stationary vehicles ahead. The theoretical collision avoidance system will only avoid the accident if the vehicle ahead was in view long enough for the LCV to brake to a standstill (or to the same speed as the vehicle ahead). The system will not avoid accidents where a vehicle pulls across its path at the last minute or where vehicles travelling in the opposite direction move across to the wrong side of the road and collide head-on, and it will be unable to steer the vehicle in any way. The system considered was not able to detect pedestrians or pedal cyclists.
- Where a vehicle for some reason leaves the lane in which it was travelling and collides with a vehicle in the on-coming lane, the lane following system is coded. This is not appropriate if a sharp steering input causes the vehicle to leave its lane.

Vehicle involvement

Figure 6 summarises the percentage of each vehicle type involved in LCV accidents in the HVCIS fatal accident database.

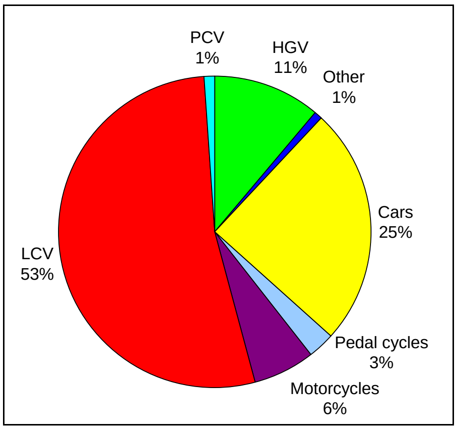

Figure 6. Vehicles involved in fatal LCV accidents (HVCIS)

Figure 6 can be compared with Figure 4 to show how representative the HVCIS data is of the national statistics. This comparison shows that LCVs account for a greater percentage of vehicles involved in the accidents. This may indicate that there are cases in HVCIS where more than one LCV is involved and less accidents where there was more than one other vehicle involved. There is also a higher proportion of HGVs and a lower proportion of cars and motorcycles, which may be a function of the cases that were available for analysis. This information should be considered when estimating potential benefits.

Accident causation factors

There are a number of factors that can influence the cause of accidents. Two of these include the vehicle drivers and the roadworthiness of the vehicles involved. The following sections describe these factors for the LCVs, drivers and fatalities involved in accidents in the sample.

Vehicle defects

It is reasonable to hypothesise that vehicle defects can be related to the age of the vehicle. Figure 7 shows the distribution of LCVs by year of registration.

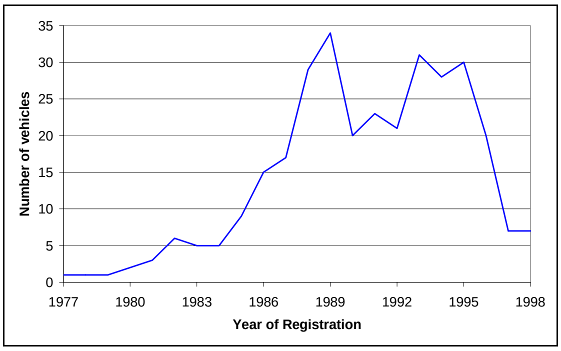

Figure 7. Year of registration of LCVs involved in fatal accidents (HVCIS)

The number of LCVs involved in fatal accidents that were registered before 1984 is low. Most of the LCVs involved were registered between 1984 and 1997. The number of vehicles registered in 1998 is very low because this is the upper boundary for the year in which the accident took place.

There were a total of 54 defects on LCVs involved in fatal accidents. Twelve, 22%, of the defected vehicles were considered to have contributed to the accident. There were eight vehicles with contributory tyre defects. These vehicles were registered between 1985 and 1994. Five of the tyre defects were because of lack of maintenance. One defect was because of previous impact damage, one was caused by a structural defect and one by faulty maintenance. There were also three brake defects that contributed to the accidents registered in 1983 and 1985, two through lack of maintenance and one caused by faulty maintenance. There was also one accident where the wing mirror was incorrectly repaired preventing it from springing out of the way if struck. This data tends to suggest that the vehicle defects are not strongly related to the age of the vehicle, with most of the defects arising from negligence with respect to maintenance. For other vehicles involved in these accidents there were a total of 26 defects, 20% of which were contributory to the cause of the accident.

Driver factors

The behaviour of 44% of the LCV drivers was considered to have contributed to the accidents. Lack of attention was the most frequent behaviour and was displayed by 24% of the LCV drivers. Almost 11% of the drivers were driving their vehicles at a speed that was considered unsuitable for the conditions. Five percent of the LCV drivers were suffering from fatigue and a further five percent made errors of judgement. Other driver behaviour factors included, but were not limited to, being under the influence of alcohol or drugs, inexperience, contravening a red light and being overloaded. Some drivers displayed a combination of the above factors.

The actions of 51% of the other drivers involved were considered to have contributed to the cause of the accident. Lack of attention was the most frequent behaviour for theses drivers, 23%, followed by excess speed, 18%, and error of judgement, 14%.

Factors contributed by the fatality

In some cases the road user that was fatally injured contributed to the cause of the accident. As with the driver factors, each fatality may display more than one of these behaviours. It was thought that the behaviour of 37% of the fatalities did not contribute to the cause of their accidents. The most frequent behavioural factor was lack of attention, 27% of the fatalities.. Eighteen percent of the fatalities did not wear the seatbelt that was provided and 16% were travelling at speeds that were excessive for the conditions. Other factors included but were not limited to, error of judgement, 9%, being under the influence of alcohol, 7%, and fatigue 3%.

Casualties

There were a total of 345 fatalities resulting from accidents involving LCVs. The distribution of fatalities by road user type is shown in Table 1.

Table 1.

Number of accidents and fatalities by road user type killed

Road user	Number of accidents	Number of fatalities
HGV	3 (1.0%)	3 (0.9%)
LCV	81 (26.2%)	89 (25.8%)
OMV	1 (0.3%)	1 (0.3%)
Car	116 (37.5%)	140 (40.6%)
Motorcycle	36 (11.7%)	37 (10.7%)
Pedal cycle	16 (5.2%)	16 (4.6%)
Pedestrian	56 (18.1%)	59 (17.1%)
Total	309	345

The most frequently killed road users were car occupants, 40.5%, LCV occupants, 25.8% and pedestrians, 17.1%. The following sections describe the types of accidents in which these road users were fatally injured and describes possible design improvements to vehicles that may avoid the accidents or reduce the severity of the injuries sustained.

Car occupant casualties

There were a total of 140 car occupants that were fatally injured in 118 accidents involving LCVs. For one of these fatalities there was no impact between the car and the LCV. The passenger in the car leant out of the window and struck their head on the back of a parked LCV. This accident has been excluded from further analysis.

The proportion of vehicles that were cars in the HVCIS sample was lower than in the national statistics, therefore it can be assumed that car occupant fatalities are likely to be under-represented. It is therefore possible that any potential benefits from countermeasure identified may be greater than estimated in this analysis.

For the remaining 139 car occupant fatalities the most severe impacts were with the objects shown inTable 2. In some cases the car may have had an impact with an LCV and then collided with a bridge. The impact with the bridge resulted in the fatal injuries and is therefore the most severe impact.

Table 2.

Impact object for most severe impact resulting in car occupant fatalities

Impact object	Number of fatalities
LCV	118 (84.9%)
HGV	7 (5.0%)
PCV	1 (0.7%)
Other vehicle	9 (6.4%)
Wide object	1 (0.7%)
Narrow object	3 (2.2%)
Rollover	1 (0.7%)
Total	139

The objective of the reported research was to consider design changes to LCVs that could reduce the number of people injured in accidents involving LCVs and the severity of injuries. Therefore fatalities caused by impacts with objects that are not LCVs are excluded from further analysis.

The following analysis considers car to LCV accidents where this impact was the most severe for both vehicles. There are 115 of these impacts because three of the most severe impacts for the car were not the most severe impact on the LCV.

Table 3. summarises the impact locations on the LCV and car for the most severe impacts between these types of vehicle.

Table 3.

Impact locations for LCV to car impacts

Impact location of car	Impact location on LCV	Number of car occupant fatalities
Back	Front	2 (1.7%)
Front	Back	5 (4.3%)
Front	Front	46 (40.0%)
Front	Near-side	6 (5.2%)
Front	Off-side	4 (3.5%)
Near-side	Unknown	2 (1.7%)
Near-side	Back	1 (0.9%)
Near-side	Front	28 (24.3%)
Off-side	Front	18(15.7%)
Off-side	Off-side	3 (2.6%)
Total		115

Front of LCV to front of car

The most frequent impact configuration is front of car to front of LCV, which accounts for 40% of the car occupant fatalities. Figure 8 shows the closing speed of the two approaching vehicles in this type of accident.

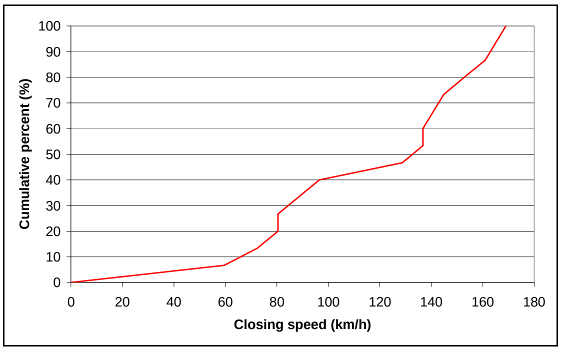

Figure 8. Closing speed of vehicles in car front to LCV front accidents

It is clear that very few of these fatalities occur in accidents with low closing speeds. Approximately 10% occur at a closing speed of up to 66km/h, which is the equivalent of each vehicle travelling 33km/h. Almost 60% of the fatalities result from impacts with closing speeds in excess of 100km/h.

The impacts are coded using part of the SAE collision damage classification (CDC) [3]. Figure 9 shows part of the CDC that can be applied to impacts to the front of the vehicle. All codes can be applied to both the front and rear of the vehicle.

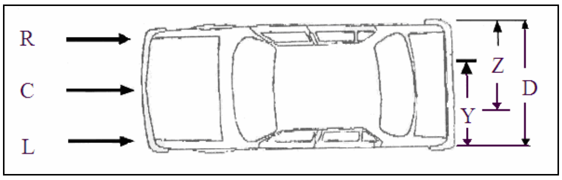

Figure 9. Part of CDC used for coding impacts

The observed damage to the vehicles taken from photographs and report was used to assess the part of each vehicle that impacted the other vehicle. Table 4 summarises the four most frequent types of front to front impact damage between cars and LCVs accounting for 63% of these types of accident.

Table 4.

Four most frequent types of front to front impact between cars and LCVs

Impact part		Number of fatalities
Car	LCV	
D	D	11
R	R	8
D	Z	5
Z	Z	5

The most frequent type of damage seen on vehicles covers the whole of the front of each vehicle. For cars this is most likely to involve a full width impact with the LCV. This would be similar in configuration to a full width full scale crash test into a deformable barrier, which is not currently included in European Regulations or EuroNCAP and is more severe than the 40% overlap that is used. However, the 50th percentile closing speed for accidents of this type is over 130km/h, considerably higher than current test speeds for cars. Also, the LCV is likely to undergo a change in velocity during the impact, which would not occur in a full width barrier test.

Table 5. summarises the potential countermeasures that may avoid accidents or reduce the severity of injuries sustained by car occupants in front to front collision with LCVs.

Table 5.

Summary of countermeasures for LCV front to car front accidents

Countermeasure	Estimate of fatality prevention		
	Quite likely	Probable	Maybe
Fit collision avoidance	2		
Eliminate defects	1		
Fit lane following system	2		1
Detect drowsy driver	1	1	
Warn of ice			1
Fit rigid FUP			2
Fit energy absorbing FUP		2	
Fit ABS		1	
Improve LCV to car compatibility			3
Prevent fire	2		
Fit automatic fire extinguisher	2		
Improve LCV to car compatibility and fit ABS		1	
Improve LCV to car compatibility and car frontal crashworthiness		1	
Improve LCV to car compatibility and car occupant wears seatbelt		1	

Front of LCV to near-side (passenger) of car

The second most frequent impact configuration was between the front of the LCV and the left side of the car. This type of impact accounts for more than 24% of the car occupant fatalities. There is very limited information about the speed of the vehicles involved in these types of accident. There were three cases where the impact speed of the car was known, two were stationary and one was travelling about 8km/h. There were eight cases where the speed of the LCV was known, which ranged from 40km/h to 64km/h. There were no cases where the impact speed of both vehicles was known. The majority of LCVs, 64%, struck the passenger compartment area of the car. Twenty-one percent of the LCVs caused damage to the rear two-thirds of the car and 11% the front two-thirds of the car. There was one case (4%) where the LCV collided with the bonnet area of the car.

Table 6 summarises the manoeuvres being performed by the two vehicles prior to the accident.

Table 6.

Vehicle manoeuvres prior to impact between front of LCV and left side of car

Car	LCV	Number of fatalities
Turning right	Going ahead other	4
Waiting to turn right	Going ahead other	2
Overtaking moving vehicle	Going ahead other	2
Going ahead on left hand bend	Going ahead on right hand bend	8
Going ahead on right hand bend	Going ahead on left hand bend	1
Going ahead on right hand bend	Going ahead other	3
Going ahead other	Going ahead other	8

For all these fatalities, the LCV was not performing a specific manoeuvre. The majority of the cars, 71%, were also not making a specific manoeuvre. In 30% of the accidents where neither vehicle made a specific manoeuvre, there was loss of steering control under braking for the car.

The most frequently injured car occupants were drivers, 43%. Front seat passengers, which were positioned on the struck side of the vehicle, accounted for 34% of the car occupant fatalities. All of the impacts that resulted in front seat passenger fatalities were to the passenger compartment or the front two-thirds of the vehicle structure, including the passenger compartment. The larger number of drivers fatally injured, when they were impacted on the non-struck side is possibly a reflection of vehicle occupancy, which was 1.60 for the period 1996/1998 [4]. Where the use of seatbelts is known, 55% of drivers and 86% of front seat passengers were wearing the seatbelts provided. The figure for front seat passengers excludes the occupant of a child restraint. There were also six rear seat occupants, three on the struck side, one in the centre and two on the non-struck side. One of the rear nearside and one rear offside occupant were wearing seatbelts.

The only countermeasures identified to be applied to the LCV involved were to fit a lane following system or to prevent the vehicle being driven under the influence of alcohol. Fitting a lane following system would probably have prevented one accident that resulted in two fatalities. Preventing the LCV from being driven under the influence of alcohol would have been quite likely to have prevented the same accident and fatalities.

Front of LCV to off-side (driver) of car

Impacts between the front of the LCV and the right side of the car were the third most frequent type of accident that resulted in car occupant fatalities, accounting for almost 13% of the fatalities. The location of the impact was mostly in the area of the passenger compartment or bonnet, 78%. Fifty-six percent of these accidents occurred when the car was turning right and the LCV was not making a specific manoeuvre. This combination was by far the most frequent. All the car occupants that were fatally injured were drivers, who were on the struck side of the vehicle. Where the seatbelt use was known, 85% were being used. Where the fitment of airbags was known, there were no side airbags fitted.

The analysis of countermeasures for accident avoidance and reduction of the severity of injuries to non-fatal for this type of accident are summarised in Table 7.

Table 7.

Summary of countermeasures for LCV front to car off-side accidents

Countermeasure	Estimate of fatality prevention		
	Quite likely	Probable	Maybe
Fit ABS		1	
Fit lane following system		1	
Fit lane following system and detect drowsy driver	1		
Detect drowsy driver		1	1
Improve LCV to car compatibility			2
Remove bull bars		1	

<u>LCV occupant casualties</u>

LCV occupants were the second most frequently killed road users in accidents that involved LCVs.

There were a total of 89 LCV occupant fatalities in the sample. Analysis of the ownership of the LCV involved in the accidents showed that where the ownership was known, 68% were being driven by an employee, 26% by the owner and 6% by someone who had hired the vehicle. Sixty percent of the LCVs involved these accidents were used for trade, 20% for delivery, 17% for roadside assistance and 3% for personal use.

In two of the accidents the LCV did not have an impact with another vehicle or object. One passenger fell from the vehicle whist trying to secure the door and the second fell from the tipping body of the LCV. Both of these accidents could have been prevented, the first one if the passenger had been wearing their seatbelt or if the vehicle had pulled over to allow them to secure the door, and the second fatality would have been prevented if they had not been riding in an unauthorised position. These cases have been excluded from the following analysis.

Impact location

Table 8 shows the impact location on the LCV for the remaining 87 fatalities.

Table 8.

Impact location of most severe impact on LCV resulting LCV occupant fatality

Impact location	Number of fatalities
Back	3 (3.5%)
Front	52 (59.8%)
Left	10 (11.8%)
Right	21 (24.1%)
Top	1 (1.2%)
Total	87

Almost 60% of these 87 LCV occupant fatalities were injured during an impact to the front of the LCV. The objects that the front of the LCVs stuck are shown in Table 9.

Table 9.

Struck objects for LCV frontal impacts

Struck object	Number of fatalities
Animal	1 (1.9%)
Narrow object	5 (9.6%)
Wide object	6 (11.5%)
HGV	26 (50.0%)
LCV	2 (3.8%)
OMV	1 (1.9%)
PCV	5 (9.6%)
Car	6 (11.5%)
Total	52

Half of the LCV occupant fatalities were caused by impacts with an HGV. Wide objects were the second most frequent impact object resulting in an LCV occupant fatality.

Although there are many more cars registered in the UK than HGVs, a higher proportion of LCV fatalities are sustained in impacts with HGVs compared with cars. This is because of the difference in mass of the collision partners. An impact between a car and an LCV is less likely to result in an LCV fatality because the LCV is heavier than the car, whereas the HGV is much heavier than the LCV and so is more likely to result in an LCV occupant fatality.

Front of LCV to front of HGV

For impacts between the front of the LCVs and HGVs, 48% of the impacts were to the front of the HGV. The closing speed for the vehicles was known in five cases and ranged from 64km/h to 156km/h. In two of these cases the LCV under-ran the front of the HGV, in one case the closing speed was estimated to be 88km/h and in the other it was 153km/h.

For the majority, 83%, of front to front accidents, both the LCV and the HGV were not performing a specific manoeuvre. In the two remaining accidents the HGV was also not making a specific manoeuvre. The LCVs in these two cases were waiting to turn right and held up.

Table 10 summarises the assessed countermeasurs for LCV front to HGV front impacts.

Table 10.

Summary of countermeasures for LCV front to HGV front accidents

Countermeasure	Estimate of fatality prevention		
	Quite likely	Probable	Maybe
Fit collision avoidance	1		
Fit lane following system		4	
Detect drowsy driver	1	2	1
Fit lane following system and detect drowsy driver	1		
Improve frontal crashworthiness			1
Wear seat belt			5
Wear seat belt and fit airbag		3	2
Improve LCV to HGV compatibility – rigid FUP		1	
Improve LCV to HGV compatibility – energy absorbing FUP	1		
Improve LCV to HGV compatibility – energy absorbing FUP and improve LCV frontal crashworthiness			1
Improve frontal crashworthiness and wear seat belt		1	

Front of LCV to rear of HGV

Forty-four percent of the LCV frontal impact occupant fatalities were caused when the LCV struck the rear of an HGV. The closing speed was known for six of the 11 fatalities and ranged from 25mph to 60mph. In three of the cases where the closing speed was known, the LCV under-ran the HGV despite a rigid rear underrun guard being fitted. There was also one case where there was no rear underrun guard fitted. There was also underrun in the five cases where the closing speed was not known. The HGV was fitted with a rear underrun guard in four of the accidents.

In accidents where the LCV struck the rear of the HGV, two of the LCVs were changing lane to their left. They collided with one HGV that was starting off from stationary and another HGV that was not making any specific manoeuvre. The remaining nine LCVs were not making any particular manoeuvre. There were four cases where the LCV struck an HGV that was parked and two cases where the HGV was held up. The three remaining HGVs were stopping, overtaking a moving vehicle or not making a specific manoeuvre.

Table 11 summarises the countermeasures considered for impacts between the front of an LCV and the rear of an HGV.

Table 11.

Summary of countermeasures for LCV front to HGV rear accidents

Countermeasure	Estimate of fatality prevention		
	Quite likely	Probable	Maybe
Prevent LCV being driven by someone who is under the influence of alcohol	2		
Fit ABS		1	
Detect drowsy driver		1	
Fit collision avoidance system	1	3	
Improve frontal crashworthiness			1
Improve frontal crashworthiness and fit airbag			1
Improve frontal crashworthiness and minimum regulatory rear underrun guard on HGV		1	
Wear seat belt			1
Wear seatbelt and minimum regulatory rear underrun guard on HGV		1	
Wear seatbelt and rear underrun guard on HGV that is stronger and lower		1	1
Wear seatbelt and energy absorbing rear underrun guard on HGV	1		1

Use of seatbelts

Of the 87 LCV occupant fatalities, 78% were driving the vehicle at the time of the accident. The use of the seatbelt was known for 84% of the drivers. Where the seatbelt use was known, 63% were not using the seatbelt provided. Therefore approximately only 50% were wearing seatbelts

Seventeen (20%) of LCV occupant fatalities, were front seat passengers. The use of seatbelts was known for 13 (76%) of the passengers. Where the use of the seatbelt was known, ten (77%) of the passengers were not wearing a seatbelt.

Of the two LCV occupants sitting in “other” seat positions (as coded in the database) one was not using the lap belt provided. The status of the second occupant was unknown. The rear-offside passenger was sitting on a wooden bench behind the driver that was not fitted with a seatbelt.

The low seatbelt wearing rate in this data could indicate that a substantial benefit may be gained from installing seatbelt warning systems in LCVs and the encouragement of seat belt use.

Load movement

There were no cases where the load was known to have moved prior to impact. There were 18 cases where the load moved after the impact. In ten of the cases the load was shed and in the remaining eight cases the load shifted.

In the cases where the load was shed, it was known that this caused injury in one case and not in eight cases. In the remaining case it was not known if the load being shed caused injury.

Of the eight cases where the load shifted, this lead to injury in two cases. In one of these cases the LCV was 8% overweight with fruit and vegetables. In the second, the load was insecure and caused the driver to be trapped between their seat and the steering wheel. There were four cases where it was known that the load shift did not cause injury and two where it is not known.

The comparison of the HVCIS sample with the national statistics showed that HGVs were over-represented in the HVCIS data. Therefore it is possible that the estimated benefits within this study of protecting LCV occupants in impacts with HGVs may actually be lower than predicted.

Pedestrian casualties

Pedestrians were the third most frequent type of road user that was fatally injured, accounting for just over 17% of fatalities resulting from accidents involving LCVs. The majority of pedestrians, 76%, were fatally injured when struck by the front on an LCV. Twelve percent had an impact with the left side and 8% with the back of the LCV.

For impacts to the front of the HGV, 73% of the LCVs were not making any specific manoeuvre. The remaining 27% were turning right, parked or overtaking on the nearside or offside

The impact speeds for LCVs in a frontal collision with a pedestrian are shown in Figure 10.

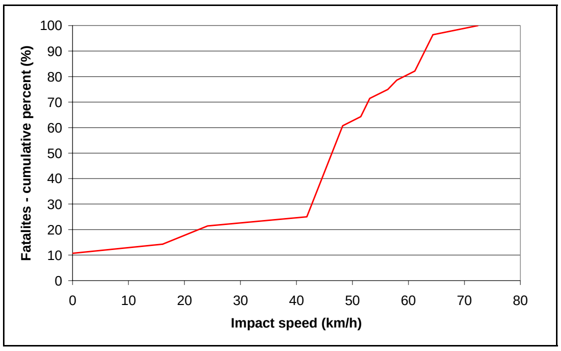

Figure 10. LCV impact speed for frontal impacts with pedestrians

Figure 10 shows that for approximately 25% of the pedestrian fatalities occur at impacts speeds of up to 40km/h for the LCV, which is the speed used for pedestrian tests for cars in EuroNCAP. For approximately 60% of the pedestrians that are struck by the front of the LCV, the LCV is travelling at 50km/h or less. The sharp increase in fatalities between 40km/h and 50km/h may be because the impact speed is taken from police records, based on eye witness accounts and reconstructions.

The most frequently selected countermeasure for impacts to the front of the LCV was to improve the design of the LCV to be less injurious to pedestrians, 26%. It was estimated that designing the front of an LCV to be less aggressive to pedestrians was quite likely to have reduced the severity of injuries for one pedestrian, probably would have prevented two pedestrian fatalities and may have prevented a further eight fatalities. The majority of the remaining countermeasures to help protect pedestrians, 48%, related to changes in the environment and the conspicuity of the pedestrians.

There were seven fatalities caused when the pedestrian collided with the left side of the LCV. Four of these fatalities were caused by an impact with the mirror on the LCV. Moving the mirrors on the LCV was considered to have quite likely prevented three of these fatalities and probably prevented one other. Making the mirrors compliant to pedestrian impact could probably reduce the severity of injuries for one of the pedestrians and may have reduced the severity for one other.

There were five fatalities where the pedestrian struck the rear of the LCV. In four of the accidents, the vehicle was reversing. In the fifth accident, the vehicle was parked and rolled back down a hill. Assessment of potential countermeasures for these accidents suggests that improving the rear vision for the driver of the LCV was considered to have quite likely prevented three of the fatalities. Improving rear vision on the LCV may have prevented one other fatality, but in conjunction with an audible reversing alarm was quite likely to have prevented the fatality.

DISCUSSION

The preceding analysis has presented the findings of a study of fatal accidents involving LCVs from the period 1995 to 1998. The HVCIS database contains 36% of the fatalities that resulted from accidents involving LCVs identified in the national statistics.

HVCIS estimate of benefits

Table **12** summarises the LCV based countermeasures and the best estimate of benefits. The six most effective countermeasures identified are shown in red. These estimates were made from consideration of the accident cases on a case by case basis. The estimated benefits relate to the number of fatalities which may be prevented for the four year period covered by the sample. The number of fatal savings is calculated using the equation below:

Number of fatal savings = (quite likely x 1) + (probably x 0.75) + (maybe x 0.25)

Table 12.
Summary of LCV based countermeasures for HVCIS sample

Counter-measure	Estimate of fatality prevention			Number of fatal savings
	Quite likely	Probable	Maybe	
Fit lane following	2	6		6.5
Fit ABS	1	8	1	7.25
Detect drowsy drivers	2	6	1	6.75
Eliminate defects	1		1	1.25
Warn of ice			1	0.25
Prevent drink driving	4			4.0
Fit collision avoidance system	3	4	5	7.25
Prevent puncture	1			1.0
Fit intelligent speed limiter		1	1	1.0
Monitor tyre pressure			1	0.25
Pedestrian friendly front	1	2	8	4.5
Wear seatbelt			6	1.5
Improve frontal crashworthiness			3	0.75
Improve LCV-car compatibility			5	1.25
Fit fire extinguisher in engine bay	1			1.0
Improve rear vision	3		3	3.25
Improve rear vision and fit reversing alarm	1			1.0
Move mirrors – accident avoidance	3	1		3.75
Make mirrors more compliant with pedestrian impacts		1	1	1.0
Improve lighting		1		0.75
Remove bull bars		1		0.75
Prevent fire	1			1.0
Improve frontal crashworthiness + other		4	3	3.75
Wear seatbelt + other	1	6	4	6.5
Improve compatibility + other	1	1		1.75
Pedestrian friendly front + other			1	0.25

There is currently no European Directive on the frontal impact protection for LCVs. Improving the frontal crashworthiness of the LCV alone was not considered to be one of the most beneficial countermeasures. However when combined with other countermeasures such as wearing the seatbelt and fitting an airbag, the benefits are substantially increased.

Estimate of national benefits

The HVCIS data sample contained an average of 86.25 fatalities per year. This figure has been used to estimate the annual benefits within the sample. These benefits can then be applied to the national figures to estimate the annual benefit of each countermeasure for the UK. The total number of fatalities resulting from LCV accidents in 2003 was 327. This figure has been used to estimate national benefits for the six countermeasures highlighted in the HVCIS sample, that showed the greatest potential benefits in Table 13.

Table 13.

Estimated annual national benefits in terms of prevention of fatalities in the UK

Counter-measure	Estimated benefits in sample	Estimated benefits per year (HVCIS)	Estimated benefits per year (UK)
Fit lane following	6.5	1.6 (1.9%)	6.2
Fit ABS	7.25	1.8 (2.1%)	6.7
Detect drowsy drivers	6.75	1.7 (2.0%)	6.5
Fit collision avoidance system	7.25	1.8 (2.1%)	6.7
Pedestrian friendly front	4.5	1.1 (1.3%)	4.3
Wear seatbelt + other	6.5	1.6 (1.9%)	6.2

The most beneficial countermeasures are ones that prevent the accident occurring. If successful, all costs associated with the accident would be eliminated. It is also suggested that such countermeasures may also reduce the severity of some accidents.

Sixty-three percent of LCV drivers and 77% of LCV passengers were not wearing a seatbelt at the time of their accidents. In Table **12** the benefit of wearing the seatbelt was assigned low probability of preventing fatalities. This is usually because of the severity of the impact causes large amounts of intrusion and no airbags. However, wearing the seatbelt in combination with some other countermeasures was considered to provide greater benefits than just a seatbelt, i.e. seat belt and air bag. The other countermeasures included, improving frontal crashworthiness of the LCV, fitting an airbag in the LCV and fitting energy absorbing rear underrun guards to HGVs.

Designing the front of the LCV to be less injurious to pedestrians was considered to be the most effective countermeasure to protect pedestrians. Initial research in this area could consider the feasibility of transferring technology that is currently being developed for passenger cars to LCVs. A low cost vehicle enhancement would be compliant or frangible mirrors that would yield when struck by pedestrian.

CONCLUSIONS

The report analysis concluded that:

- In STATS19
  - car occupants were the most frequently killed road user group. The proportion of LCV occupants and pedestrians were very similar to each other and were the second most frequently killed.
  - Vulnerable road user casualties, such as pedestrians and pedal cyclists, were over represented when considering serious and fatal LCV accidents.
- From the HVCIS sample
  - Car occupants are the most frequently killed road users in LCV accidents, followed by LCV occupants and then pedestrians.
  - The use of seatbelts in LCVs is lower than for car occupants, 47%. If five (5.6%) of the LCV occupants had been wearing seatbelts at the time of their accident, they may have survived. The potential benefits of wearing seatbelts can be enhanced when worn in conjunction with other developments in the safety of LCVs such as improved crashworthiness and fitment of airbags.
  - Encouraging seat belt wearing in LCVs also has the advantage that this countermeasure is financially inexpensive and could be very cost effective.
  - Re-designing the front of the LCV to protect pedestrians in an impact was considered to be the most effective countermeasure for reducing the number of pedestrian fatalities in accidents with LCVs. Research could consider the feasibility of technology transfer from the passenger car industry.
  - Development of mirrors that are less aggressive to pedestrians would also provide benefits.
  - Overall, accident avoidance countermeasures such as fitting ABS, preventing departure from the lane of travel or fitting collision avoidance systems were considered to provide the greatest benefits, with ABS and collision avoidance systems both estimated to be capable of preventing approximately 7 fatalities per annum.
  - Without performing further research or a detailed cost benefit study, it is suggested that:

    - Reductions in fatal injuries could easily be achieved through the increased use of seatbelts, possibly supplemented by fitment of airbags.
    - Further consideration, maybe with further research, should be given to improved braking (i.e. ABS), lane following, alertness monitoring, collision avoidance and consideration of pedestrian impacts.

RECOMMENDATIONS

Future research on the safety of LCV may wish to focus on:

- A detailed cost benefit study for the important countermeasures discussed in this paper
- The feasibility of technology transfer from the car industry with respect to pedestrian protection, crashworthiness and compatibility.
- The assessment of ABS for LCVs
- Considering application of future lane following and collision avoidance systems for cars and HGVs to LCVs.

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ENHANCED COACH AND B US OCCUPANT SAFETY

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ABSTRACT

In the EC countries approximately 30000 persons are injured as bus or coach occupants in accidents with transportation in the size of more than 5000 kg every year. Some 150 of these persons suffer fatal injuries. The kind of accidents which occur throughout EC countries cover collisions, single accidents as well as "normal" driving manoeuvres.
This study describes the results of an analysis of coach and bus occupant safety research and regulatory practices in Europe. The focus of this work is on occupant protection in several types of buses and coaches in both the scheduled and non-scheduled transportation.
For this purpose the connection between the occurrences at the real world accident scenes and the mandatory test methods has been analysed. The simple reason for that approach was the important feedback and usable knowledge of the accident incidents and their influence to improve current test procedures. Therefore an investigation was conducted on a number of topics including statistical collision data analysis, development of a bus accident database, reconstruction of real world accidents by means of an accident reconstruction software, component testing, full scale bay section testing, development of numerical simulation models for vehicle structure and occupant behaviour, parameter studies on occupant size influence, detection of injury mechanisms, cost benefit analyses for different test methods and finally the suggestion for improvements of current testing practices.
The main approach of this research work is the development of enhanced bus safety. This shall be obtained through the European Regulatory Agencies and ISO standard committees as this work will deliver the bases for new and released regulations. Some of the results of this study have already been taken to table an amendment to a current directive and will further be used to propose necessary improvements and additional research subjects either.

INTRODUCTION

This study describes the results of an analysis of coach and bus occupant safety research and regulatory practices in Europe. The focus of this work is on occupant protection in several types of buses and coaches in both the scheduled and non-scheduled transportation.
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Therefore an investigation was conducted on a number of topics including statistical collision data analysis, development of a bus accident database, reconstruction of real world accidents by means of an accident reconstruction software, component testing, full scale bay section testing, development of numerical simulation models for vehicle structure and occupant behaviour, parameter studies on occupant size influence, detection of injury mechanisms, cost benefit analyses for different test methods and finally the suggestion for improvements of current testing practices.

In total seven ECE (Economic Commission for Europe) regulations and 5 corresponding EC directives deal currently with the structural and seat design for buses and coaches.
Therefore the general objective of this work was to generate new knowledge to minimize the incidence and cost of injuries caused by bus and coach accidents.

This objective is relevant for:

- the bus industry since it will bring them safer buses
- the insurance industry since it will reduce their costs
- society due to the decrease in incidence and severity of injuries to bus and coach occupants

Additional emphasis was put on the various passenger sizes, in order to consider optimisation of restraint designs for occupants other than the 50th%ile male. There are currently no data relating specifically to the requirements for, or performance of, child restraint systems for children in buses. As various sizes of buses are used for public transportation different groups will be investigated according to ECE (M2-up to 5 tons and M3-more than 5 tons)
Special emphasis was also put on so called "City buses", where passengers are often standing. In

these buses injuries are the result of crashes and also vehicle operation, such as emergency braking, when injuries occur due to impacts of passengers against components of the bus interior.
Suggestions for new written standards, which increase the safety of buses, and which demonstrate and prove the increased safety were the major result of this research work. They are based on the developed and evaluated new and extended test methods. Their efficiency was demonstrated through numerical models of an improved bus design.

METHODOLOGY

Following study gives an overview of the technical state of the research work on bus safety with emphasis on the main achievements. The structure of the paper represents the chronology of the performed work.

Statistical Collection

First step was the analysis of statistical accident data. This was done by using the data from representative countries (Austria, Germany, Great Britain, Italy, the Netherlands, Spain, France and Sweden).
Firstly the numbers of casualties in buses and coaches were compared to the national pictures to give a measure of the relative importance. For the years 1994 to 1998, on average, approximately 150 bus or coach occupants were killed per year in the eight countries in the study as a whole. Fewer bus or coach occupants were injured than car occupants and in all the countries, when a casualty occurred in a bus or coach, the injury is likely to be less severe than for the whole road casualty population. From 1994 to 1998 the number of casualties has risen in the Netherlands, France, Spain and Sweden.
The bus and coach casualty population was then considered, by age, gender and injury severity. In all eight countries many more women than men were injured overall but this trend is not necessarily borne out in fatality figures. In all represented countries men have a greater likelihood of a serious or fatal injury when an injury occurs, with their ages more evenly distributed than those of female casualties. In some countries peaks in age can be ascertained at school age and towards elderly age, the latter being more obvious for female casualties than male casualties. The position of casualties was then investigated. More passengers were injured than drivers in all countries. In France, Germany and Great Britain a higher proportion of driver casualties sustained a serious or fatal injury than passenger casualties. The circumstances of bus and coach accidents with injured occupants were then studied. This specific study has been able to support further work in this study on rollover and frontal impacts whilst also identifying the need to appreciate the high levels of non-collision injuries seen in Austria, Germany and Great Britain (especially for elderly passengers).
From the data available with definite rollover/overturning data fields it has been established that these types of accident don't happen very often but when they do the number of seriously injured occupants can be high. Frontals are less serious in terms of injury than rollover/overturning but they happen more often and make up a large proportion of the casualty populations. It is also apparent that collisions with trucks are a significant influence on the fatal injury experience of bus and coach casualties. For the countries with data available most casualties occurred on urban roads; however most fatal injuries occurred on rural roads.
Data were also analysed on environmental conditions at the time of the injury accident to investigate when and in what weather conditions injuries occur.

Selection of cases for in-depth study

The outcome of the statistical collection supported the definition of the cases for the in-depth analyses. Although the access to real accident data was limited a reasonable number of cases could be analysed. This information was stored in a particular database for further process.

Accident reconstruction

By means of accident reconstruction software tools, especially PCCrash and SINRAT the selected cases have been analysed. For this purpose the accident involved vehicles and obstacles were loaded from a special database. Sketches or photographs of the accident scene (Figure 1) which showed the end position of the vehicles and the tyre marks were loaded too. After defining the operation sequences, the correct boundary and the initial conditions the calculations were performed. The results were shown in tables, diagrams as well as 3-dimensional video clips.
Figure 2 shows a simulation sequence of a frontal impact between a bus and a tree. The accident was caused by a car driver from the ongoing traffic who entered the wrong lane and hit the bus in the left front area.

Figure 1. Photographs of accident scene and marks on the street

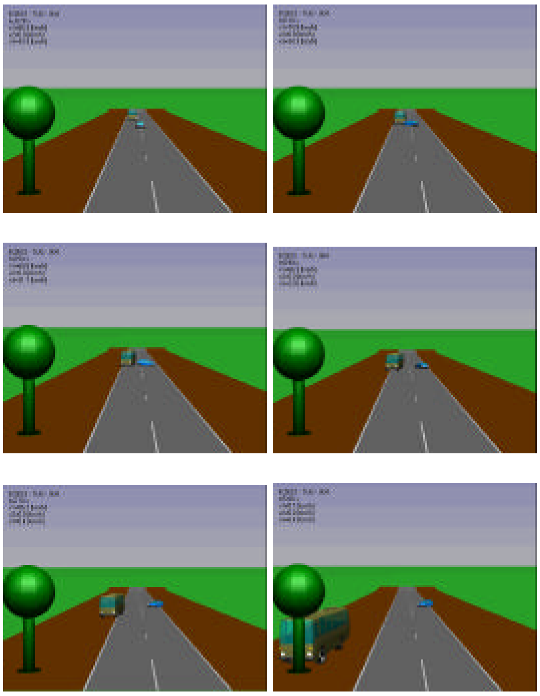

Figure 2. Accident reconstruction

Component Tests

As preliminary work on the FMH testing a huge number of photographs were taken from several bus interiors to show current European bus design. Based on this work a proposal was generated, describing the performance of the free motion headform testing. The tests were performed using several bus parts, where head contact is possible and can be critical due to injury risk.

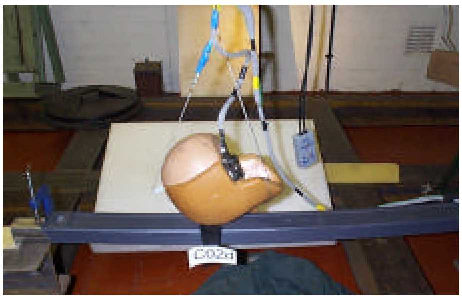

Figure 3. FMH testing

These test were done to measure accelerations and loads as well as to calculate the injury criterion HIC.

In addition to these bus interior component test two series of tests on bus seat crash behaviour were performed.

One series focused on basic seat material tests and the frontal impact behaviour (Figure 4), The tests in frontal direction were performed according to the ECE R80 conditions, varied by different configurations of the dummy placements.

Figure 4. Frontal impact testing

The rear impact tests (Figure 5) have been performed as new approach in seat testing. Background was the analyses of the seat behaviour, either in rear end impacts or in frontal impacts, when the seats are rearward faced.

Figure 5. Rear impact testing

Full Scale Reconstruction

The first performed full scale test has been a rollover test on a M2 bus. This kind of testing represents a new approach, since such a test is currently required only for M3 buses. The boundary conditions were the same as for a standard ECE R66 test. A further new approach was the usage of 2 dummies for measurement purposes. The second test has been a frontal impact pole test (Figure 6).

Figure 6. Frontal impact and rollover testing

Numerical simulation model for vehicle structure

The study of Cranfield involved creating a detailed finite element model of a M2 minibus (Figure 7) that was previously tested in the full scale test. The model was set up to simulate the two full-scale reconstructions ie. rollover conforming to ECE Reg. 66 and frontal impact into 60cm diameter pole barrier.

The main criteria for the model validation were the acceleration pulses obtained from the full-scale test vehicle. A comparison of the simulation and test values showed that the peak values and general trends were very similar between test and simulation.

Figure 7. Frontal impact and rollover model

The numerical bay section models from PoliTo were developed using MADYMO software. For the model shown on the right side both rigid bodies and finite elements were employed. The vertical and the roof pillars were modelled using rigid bodies connected each other by revolute joints. The lower part of the bay section was modelled using one rigid body because it was observed that this part has very small deformations during the rollover.

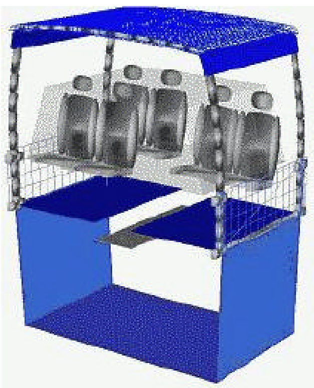

Figure 8. Bay section rollover model

Numerical simulation model for occupant behaviour

Cranfields rollover occupant model (Figure 9) simulated one of the 50th percentile Hybrid III dummies that was inside the full-scale M2 rollover reconstruction. The dummy was seated away from the contacted side of the vehicle and wearing a 3-point belt with the shoulder belt over it's right shoulder (ie. the side closest to the ground contact).

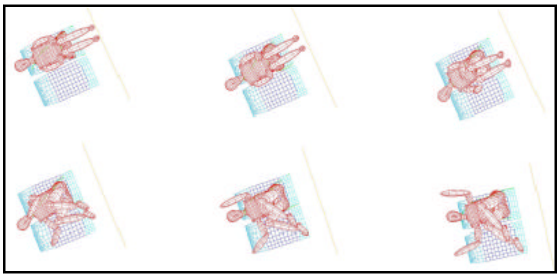

Figure 9. Rollover simulation (M2 bus)

The frontal impact occupant model (Figure 10) simulated one of the 50th percentile Hybrid III dummies inside the full-scale M2 frontal impact reconstruction. The dummy was seated in one of the original minibus seats, with an unoccupied seat directly in front. The seat characteristics (geometry, breakover stiffness and pitch) were taken from the tested vehicle. The model consisted of a validated Dyna3D Hybrid III dummy model, seated in a double seat, with a double seat in front.

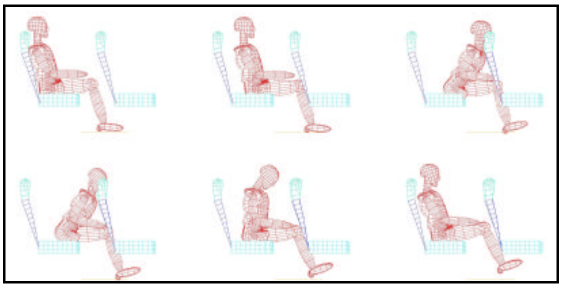

Figure 10. Frontal impact simulation (M2 bus)

INSIA created two types of numerical models, one consisting in the bay section occupants and another without occupants. For the case of bay section with occupants several models were developed to determinate how the usage of a two points belt system and the original position of the occupant may affect to the severity of the injury suffered by the occupants.

This model was validated through a rollover test of ECE R66 performed in the INSIA facilities with a coach body section. The structure accelerations and deformations were used for validating the model. As a conclusion of the model without occupant validation it have been proved that the deflexion results are very similar in the model and in the test.

Some of the accelerometers signals are similar in terms of behaviour (when the maximum and the minimum are reached) although the value is different.

This model was validated through a rollover test of ECE R66 performed in the INSIA facilities with a bay section that has been loaded with passengers, and equipped with an instrumented EuroSID-1 dummy. The effect of passenger's mass was represented by 7 ballast masses (68 kg).

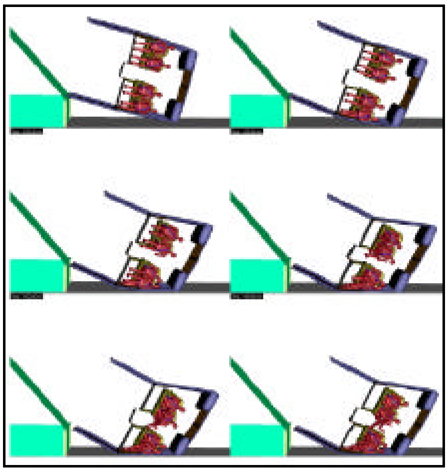

Figure 11. Rollover simulation (bay section)

The structure accelerations and deformations and the dummy signals registered during the test are used to validate the model. The model parameters of the structure are the same used in the previous test. To simulate the ballast and the EuroSID used in the real test, four EuroSID dummy models were placed in the front seats row of the structure.

TUG created a numerical occupant model to simulate the occupant kinematics in different kinds of City bus interior designs under usual non collisions incident situations like emergency braking, driving manoeuvres and acceleration jerks. By editing the predefined data files various kinds of City bus configurations can be generated. Especially the seat systems e.g. single seats or complete seat rows in line or in opposite configuration and the retaining systems like grab rails and space dividers can be modified and varied. The results of these calculations enabled the evaluation of the movement of the occupant, the detection of possible impacts with interior parts and the loads to the dummy.

The numerical simulation model for occupant behaviour represents a good possibility to analyse the injury potential of city bus interior areas during an extreme driving manoeuvres e.g. emergency braking.

For these purposes the interior of a city bus was generated (Figure 12) by means of a several multi-body systems within the MADYMO software.

The validated dummies, in seating and standing configuration were also taken and adapted from the MADYMO database. For the calculation of real world driving situations, the trajectory of the centre of gravity of the vehicle is determined by means of the accident reconstruction software PCCrash.

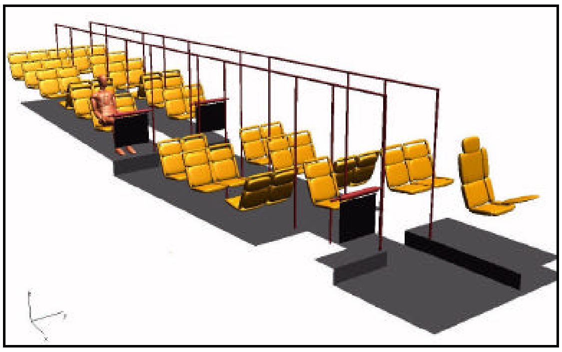

Figure 12. City bus model

By implementation of a special transformed coordinate system, the data from PCCrash can directly be taken as input data. The validation of the numerical model was performed by using the data of experimental tests. The resultant acceleration curves from the experimental free motion headform tests were used to define the contact functions of the model. Since only one head drop test was performed per interior part and no videos were available the validation is mainly based to quantify and to compare the injury risk during different impact situations. Although these results are generated with a simplified model, they are quite sufficient to detect lacks of safety matters.

Cause of injury summary

This work takes an overall view of the real world accident data and investigates the results of the numerical simulations to establish the injury mechanisms that are causing problems in M2 and M3 vehicles. At the national level though no information was available on injury severity to different body regions. Therefore analysis has been carried out using the in-depth study of 36 accident cases. As this database was created from available accidents and was not sampled the injury distributions are not comparable to the national pictures and therefore absolute figures of risk cannot be taken from the data. Care must be taken with the results from such a small number of cases, which are very diverse in their nature (e.g. different crash scenarios, classes of vehicles, occupant characteristics, restraint use). A general picture is formed though of which body regions are more susceptible to injury in M2 and M3 accidents. The results of simulations performed were used to illustrate possible contacts and the injury criteria of the dummy models indicate where injury criteria limits are being exceeded.

Parameter study

This task has been carried out to investigate the influence on injury risk when certain key parameters, such as vehicle structure, seat characteristics and stiffness are changed. These results indicate areas of the vehicles that could be improved and may be adding to an injury mechanism at the moment. Using the in-depth database it is possible to get injury data to body region level and from tests and simulations it is possible to analyse dummy movements to realise general dynamics.

Numerical test methods

This task was undertaken by Cranfield in order to investigate the strength of the superstructure of a typical coach under rollover conditions. In particular the validated, with experimental evidence, finite element model of a coach bay section consisting mainly of three dimensional highly non linear beam elements was used for a parametric study and further detailed modelling of some simplified features used to assemble this model. Also several finite element detailed models were created in an attempt to obtain theoretical information for the bending only, structural behaviour of components and joints.

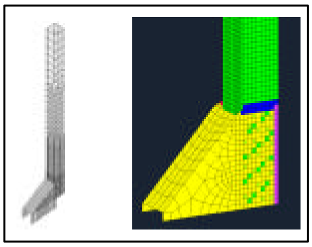

Figure 13. Pillar - structural behavior

The conclusions obtained by INSIA in relation to the structural numerical test for rollover of coaches are described. The results from the rollover tests have been analysed and compared, and new developed models have been used.

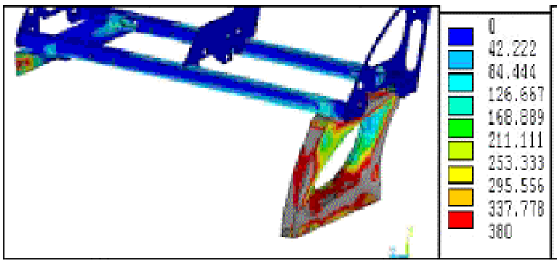

Figure 14. Seat frame - Structural behaviour

On the one hand, the effect of the belted passengers over the structural deformation and energy absorption has been quantified, and the way to introduce it in the numerical models has been discussed. On the other hand, it has been analysed some possible problems of different techniques for structural models, and some guidelines are proposed for the model conditions and the required validation tests.

PoliTo performed simulations by using the numerical models of the CIC coach bay section. A study was performed to verify the effects of some parameters relevant for the structural tests in order to point out the need of parameter specifications and the possibility of changes in the test conditions. In this way new structural tests could be figured. Investigation parameter were amongst others the moment of inertia, the falling height, the impact inclination and number of jointed bay sections.

This task was undertaken by TUG in order to extend the numerical models for vehicle structure and occupant behaviour so that the results of component tests which allow the definition of structure and design can be adopted to the individual bus in a rather simple manner. The numerical simulations demonstrated an easy approach to evaluate the interaction between passenger movement and deforming roof structure during a rollover impact. This tool can be used as pre-check of a new coach model both for assessment of the structural roof deformation and the contacts between occupants and the intruding structure.

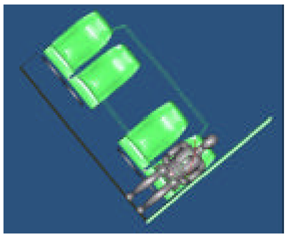

Figure 15. Rollover occupant behavior

Component test methods

CIC`s guidelines for Free Motion Headform (FMH) drop tests have been developed for city-buses, coaches and minibuses, through the use of experimental data and numerical simulations. The following steps have been undertaken: a) Numerical FMH models (Figure 16) were created and validated and used assess the influence of different impact speeds; b) A list of interior components commonly impacted by occupants for each vehicle type was compiled, including typical methods of construction and suggested methods of improvement; c) Head impact velocities and angles of impact were obtained from the numerical occupant models and used to define FMH test guidelines; d) FMH tests on a typical coach interior component were performed to assess the influence of impact speed, angle, local stiffness and possible padding.

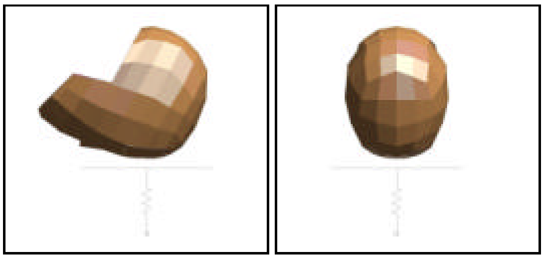

Figure 16. FMH simulation model

TNO's work focused on frontal impacts where the main interaction is between the passenger and the restraint system, the forward seat, a bulkhead or other solid object. Although this is a very limited subset of all injury causing loading conditions, it seems to be the only one for which the suitability and optimisation of restraints systems makes sense. Based on the best compromises between wearing a 2 point or a 3 point belt system, the use of 3 point belt systems is recommended for adult and child occupant passengers in buses and coaches.

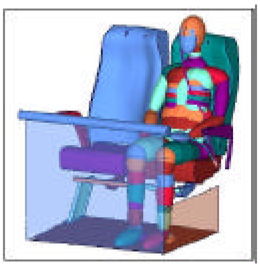

Figure 17. Frontal impact simulation model

TUG investigated the behaviour of sitting occupants under rear impact conditions. That can occur both for forward faced seats under rear end impact and for rearward faced seats under frontal impact conditions. TNO's validated frontal impact seat model formed the basis for the further detailed modelling to create the rear impact model. The numerical seat model describes a geometry of a rigid platform and 2 rows of coach seats, one behind the other. This configuration corresponds to the performed rear end impact sled tests. The objective of the analysis was to investigate the injury risk in that type of impact incidence and to detect and point out the weak points.

Figure 18. Rear impact simulation model

Full-scale test methods

The aim of this specific work was to gain a better understanding of how the mass of passengers may effect the deformation of a coach structure during the UN-ECE Regulation 66 rollover test procedure. Therefore Cranfield calculated the proportion of the occupant mass that is effectively coupled to the coach during an R66 rollover test for various passenger restraint configurations (unrestrained, lap-belted and 3-point belted) and to assess the influence of the passenger mass on the deformation of a typically fully laden coach.

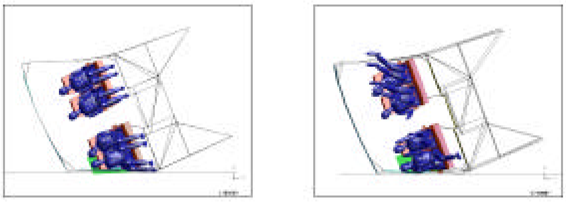

Figure 19. Bay section simulation model

INSIA's work describes the conclusions obtained in relation to the extended rollover test of coaches. The results from the rollover tests and simulations have been analysed and compared. It is quantified for different types of buses the energy increase that the superstructure must absorb because of the influence of the use of safety belts to fulfil the requirements of Regulation 66. Two different rollover test methods that let take into account the influence of the use of safety belts in buses and coaches already proved in previous tasks are presented. Other subjects such as the preparation of the bus to perform a full scale rollover test, the energy absorption capability of the seats and the driver's place are discussed.

TNO´s preliminary feasibility study of the driver/co-driver safety in case of frontal collisions by performing MADYMO simulations and if possible to propose first ideas for evaluating the "survival space" for driver/co-driver during a frontal impact. The feasibility study on the use of ECE/R.29 type of tests, even when a large margin of uncertainty is taken into account, has learned that current upper bus structures are far away from being crashworthy for frontal impact.

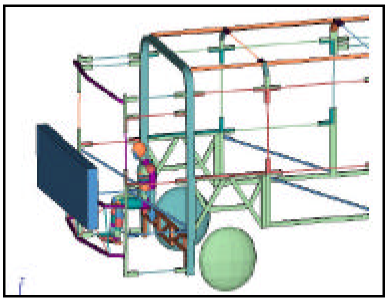

Figure 20. Frontal impact driver model

Test procedures for city-buses

This task was undertaken in order to draft a proposal for a basic test procedure for bus interior to measure and limit the impact load for standing, sitting and moving people especially under the conditions of an extreme driving operation namely the emergency braking.

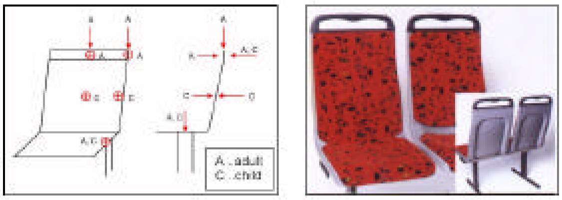

Figure 21. Proposal for test procedure

Cost benefit analysis of different test methods

The following part describes a cost/benefit analysis for different test procedures according to the current Regulations ECE R66 and ECE R80. Previous studies of this work revealed that, apart from the prescribed safety requirements in the mentioned regulations, a number of additional improvements can be suggested. The recommendations refer, for instance, to the use of seat belts, performing test procedures with dummies, etc. The cost/benefit analysis assessed on the one side the required costs for tests and simulations, considering the extension of the ECE R66 and ECE R80 with the additional improvements. On the other side, the analysis estimated the reduction of socio-economic costs due to less fatalities and seriously injured occupants in rollovers and frontal/rear impacts if safety requirements as prescribed in the improved Regulations are fulfilled.

Table 1.
Estimation on achievable tests versus required tests

Regulation No.	Type of Test / Simulation	Required tests per year in EU	Achievable tests	Achievable tests / Required tests
ECE R66*	Bay section	408 - 1224	2912 - 5698	4,6 - 7,1
	Full scale	408 - 1224	190 - 320	0,3 - 0,5
	Simulation	408 - 1224	422 - 3333	1,0 - 2,7
ECE R80*	Sled tests	4080 - 8160	2730 - 8635	0,6 - 1,0

In addition, the number of tests required for type approving all buses and coaches in the EU per year was estimated using the production figures for buses in the year 2000. The number of theoretically achievable tests could be determined on the basis of the saved socio-economic costs and the required costs for tests. The study showed that, apart from small exceptions, the socio-economic costs saved due to less fatalities and seriously injured bus occupants in rollover and frontal/rear impact accidents would be sufficient to cover the annual expenses needed for performing tests/simulations for type approving all produced buses and coaches. The report closes up with a theoretical consideration regarding the acceptance for bus and coach accidents, underlining the necessity of more tests and simulations.

Mathematical model of improved bus design

The objective of this task was to demonstrate the best practise design for M2 vehicles involved in frontal impact and rollover accidents. The original minibus vehicle from Cranfield was considered to perform well for both frontal impact and rollover. The frontal impact test into a barrier was an aggressive scenario resulting in a survivable accident for all the passengers, with just the driver’s compartment intruded. The rollover according to ECE R66 was passed comfortably due to stable roof cross beams. The scope of this task was not to assess or modify the structural performance of the M2 vehicle, as this would require far more time and effort to achieve. Instead, the original structural performance was accepted as a good design for which the interior could then be optimised.

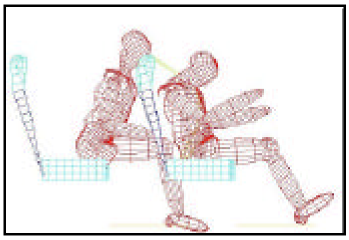

Figure 22. Improved M2 bus model

INSIA created a mathematical model that allows simulating the dummy response in a bay section rollover test according to the ECE-R66. In order to study the influence of different structures, the structure’s model is made in parametric way. With the intention of to study the influence of the location of the dummy and its response, several models were developed with the dummy placed in different locations and also with different restraint systems (two points belts and three points belts).

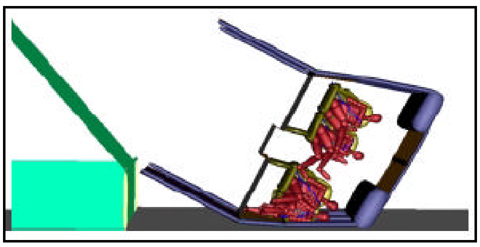

Figure 23. Improved bay section model

This part performed by Polito reports on the influence of the passengers mass on the results of a standard ECE66 rollover test. As a result of this study a K factor was calculated to represent the percentage of the passengers mass coupled to the structure during a rollover using different restrain systems (two point and three point belt).

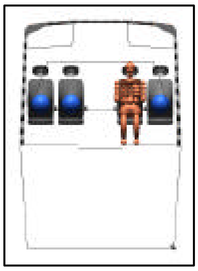

Figure 24. Improved bay section model

This work described the approach from TNO to evaluate possible improvements to the existing ECE/R80. All simulations were oriented towards the final objective of providing design guidelines (recommendations) for bus seats as far as 3 points belt system requirement is involved. It seems to be necessary to update ECE/R80 with respect to 3 points belt systems and the necessity to check their adaptation to children and small occupants. It must be verified if ECE/R.44 is able to certify safety of three point belt adaptable systems or if this needs to be addressed in ECE/R.80.

Figure 25. Improved frontal impact model

This task was undertaken by TUG in order to draft design guidelines which represent a better (safer) impact behaviour for the sitting or standing occupants. For this purpose a new developed numerical city bus model including all important components of bus interior was taken for a parameter study varying the material characteristics, interior designs and the occupant sizes

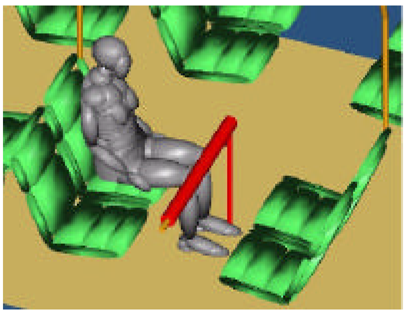

Figure 26. Improved city-bus model

ADDRESSED STANDARDS

The Economic Commission for Europe (ECE) of the United Nations elaborates the list of regulations known habitually as Geneva Regulations (www.unece.org/trans/main/wp29).
The European countries can adhere in a voluntary manner to each of these regulations, which will be mandatory in a particular country only if they are explicitly incorporated to his national regulation.
The European Directives are mandatory for all the members of the European Union when they are included in the Directive 70/156-2001/116/CE (homologation of the vehicles that includes the list of particular Directives for each type). Those Directives are issued by the European Parliament, Council or European Commission depending on the case, and they are approved in Brussels (www.europa.eu.int/comm/enterprise/automotive/directives/vehicles).
Table 2 below shows the actual European Directives and Regulations that can be affected by the recommendations made from the research done inside this study.

Table 2
Actual European Directives and Regulations

		European Directive	ECE Regulation
Obligatory use of eat belts		91/671 – 2003/20/EC	
Seat belts anchorages		76/115 – 96/38/EC	14 R05
Seats, seat's anchorages and head restraint		74/408 – 96/37/EC	80 R01
Safety belts and restrain systems		77/541 – 2000/3/EC	16 R04
General construction of large passenger vehicles	> 22 + 1	2001/85/EC	36 R03
	< 22 + 1		52 R01
	Double-deck		107 R00
Rollover resistance			66 R00

SUGGESTION FOR WRITTEN STANDARDS

This paragraph describes the suggestions for written standards in detail. These proposed improvements and ideas are based on the whole research carried out during this study. Main inputs were the results from the accident analysis, the component tests, the numerical simulations and the parametric studies. The following description is subdivided in 3 chapters, namely two to address directly existing regulations (rollover / frontal impact) and one for new and open issues.

Rollover

Use of seat belts is strongly recommended

The performed accidents analysis indicated that a part of the injuries in rollover accidents are caused by the impact of the occupants on the side panel and on the luggage rack and also by the effects of occupant interaction. The number of injured occupants and the injury severity of the casualties is less if the bus is equipped with a proper seat restraint system on condition that the belts were used. Studies based on the performed simulations indicated that at least a 2-point belt retains the occupants in their seats and avoids their free movement inside the vehicle during a rollover for three seat positions that are not closed to the impact side. The differences between lap belts and 3-point belts have been analysed and it can not be determined which of them is better under rollover conditions. When the passenger is situated in the rollover side near the aisle, a three point's belt could avoid the impact of the head with the side window. At least a lap belt increases the passengers' security under rollover. There are no recommendations of modification in the numbers of seat belts anchorages (2- or 3-points) that must be obligatory and the conclusion is that the actual regulations are sufficient for that point.
(Targets: Directive 2003/20/EC, Directive 96/38/EC, Directive 2001/85/EC, ECE 14R05, ECE 66R00)

Mass of belted occupants has to be considered for calculation and testing

The investigations within this study indicated that the introduction of belted passengers increases the energy to be absorbed during rollover significantly. That fact must be taken into account in the requirements made to the superstructure in the current Directives and Regulations. The influence of the belted occupants must be considered by adding a percentage of the whole passenger mass to the vehicle mass. That percentage depends on the type of belt system and is 70% for passengers wearing 2-point belts and 90% for passenger s wearing 3-point belts. The mass must be considered as rigid joint and must be fixed at the theoretic centre of gravity of the passengers (about 200 [mm] above the cushion or about 100 [mm] above the R-point. Those 2 factors (the increment of the total mass and the height of the centre of gravity) increase the energy to be absorbed during rollover and must be taken into account in the tests and the calculation methods either.
(Targets: Directive 2001/85/EC, ECE 66R00)

M2 buses included in the rollover test

The regulation 66R00 will be applied to single-deck rigid or articulated vehicles designed and constructed for the carriage of more than 22 passengers, whether seated or standing, in addition to the driver and crew. With the scope defined, vehicles of less than 22 passengers and double-deck vehicles will be not obliged to be approved according to R66 prescriptions. Another idea could be to define the scope according to masses and/or dimensions of the vehicle, as another regulation do. With the scope defined vehicles 10 [m] length but with only 20 passengers are not obliged to be approved according to R66 prescriptions. As tests have proved, a good designed M2 vehicle pass the rollover test nowadays. The proposal is to include M2 and M3 vehicles in the scope of rollover test.
(Targets: Directive 2001/85/EC, ECE 66R00

Child safety (adaptation of the restraint system)

This chapter deals basically with the same claim as child safety during frontal impact. It was proved as necessary to restrain children by means of an adapted belt system to protect them well. Main goal is the avoidance of ejection through side window or windshield and naturally also the protection of an uncontrolled free movement inside the bus.
(Targets: Directive 2001/85/EC, ECE 66R00)

Pendulum test should be deleted

Regulation 66 permit the evaluation of the rollover resistant of the structure by a full vehicle rollover test, bay section rollover test, calculation methods of by a pendulum test. Comparing the results obtained from simulations from rollover tests and pendulum tests it was found that at the end of the deformation process the energy absorbed by the joints is higher for the pendulum. Therefore, the two testing procedures are not equivalent and the less realistic pendulum test should be deleted.
(Targets: Directive 2001/85/EC, ECE 66R00)

Frontal / Rear End Impact

Use of a 3-point belt system is recommended

It is recommended to prevent the contact between passenger head and seat back in front in most cases. The validated models for frontal impact showed that, even for crash pulses higher than the 80 regulation one, which should be prevented when using a 3-point belt. The use of a 2-point belt produces a higher neck extension moment for a frontal impact than a 3-point belt. Attention must be paid to the correct restraining of children.
(Targets: Directive 2003/20/EC, Directive 96/38/EC, Directive 2001/85/EC, ECE 14R05, ECE 66R00)

Rigid platform for seat testing

Both the vehicle floor and the seat structure affect the crash behaviour of the combination to be tested. To avoid having to tailor the bus seat of a certain seat manufacturer to the various bus and coach structures, the bus seats should be designed for a

rigid floor structure that does not absorb energy during impact. Test performed on a combination of a rigid vehicle floor structure and seats specifically tailored to this structure are applicable to all kind of different floor structures. A special rigid floor structure and wall rail system should be defined for performing sled tests according to the regulation and directive.
(Targets: Directive 96/38/EC, ECE 80R01)

Combination test for seats
A sled test configuration could be: 2 rows of seats, the front seat (first row) with restrained passengers (50%ile dummies) and the auxiliary seat (second row) with unrestrained and restrained passengers. In practice it will be difficult to decide what the worst case configuration should be, because it depends on the type of seat. Therefore, it is recommended to perform at least two impact tests.
(Targets: Directive 96/37/EC, ECE 80R01)

Crash pulse for M2 vehicles
The best practise M2 restraint system is the 3-point seat belt. This has been proven for both frontal and rollover accidents. The 3-point belt allows the major body parts of the occupant to be directly coupled to the seat, giving a greater degree of control over the occupant's movement during a crash.
In order to achieve this control and therefore have an effective restraint system, the seat must also be capable of withstanding the loads transferred to it by the belt system. For frontal impact in an M3 coach this requires the seat + belt to adhere to ECE R80. It is proposed that a similar test should apply to M2 vehicles bus using the slightly higher test pulse developed by another EC project.
(Targets: Directive 96/38/EC, Directive 2000/3/EC, Directive 2003/20/EC, ECE 80R01, ECE 16R04)

Child safety (adaptation of the restraint system)
From the summary of ECE R80, it is clear that no interest is given to the necessary adaptation of 3-point belt systems to children or small occupants. This probably is the main concern related to this regulation, because wearing not adapted 3-point belt systems can not be considered as a solution for children. It seems therefore necessary to update the regulation and directives also with respect to 3-point belt systems and the necessity to either check the suitability of the belt system for children or to limit the access to 3-point belts for children.
(Targets: Directive 96/38/EC, Directive 2000/3/EC, Directive 2003/20/EC, ECE 80R01, ECE 16 R04)

Proposals for new Regulations

Even though the important progress related to the regulations and directives to homologate buses and coaches during the last years, and the increase on technical advances implementation and in the safety level of those vehicles, there is still a considerable gap from research, technological implementation and active and passive safety in vehicles of category M1. Although the accident statistics indicate that the transport by bus and coach is the safest mode of road transportation, there are still some important points that could increase the security level of that type of transport and that are implemented or advanced in other types.

Research for driver / co-driver frontal impact safety
The analysis of the real world accidents indicated that the occupants in the first row (driver, guide) can be ejected through the front window, or affected by the intrusion of coach elements. Assuming that both the driver and co-driver are belted, the major problem is the energy absorption of the frontal area and the intrusions through the wind screen.
The special risk of the driver's workplace in a lot of accidents, like frontal collisions, can be higher than the passenger's one. On the other hand, if the drivers were correctly protected, in such way that they remained conscious and were not seriously injured, they would keep the control of vehicle in manoeuvres after the accidents and would make easy the evacuation.
Special protection devices should be designed for the driver protection in the frontal of the coach because the driver's safety is not adequately considered in current regulations.
The research carried out with a frontal coach impact at 25 [kph] and the current R29 regulation (Protection of the cabin occupants in an industrial vehicle) has demonstrated that the actual designs are not capable of absorbing the applied energy. More research is needed to define the requirements for the structure, a suitable test for buses and to modify the actual designs to preserve the integrity of drivers in frontal of front-lateral impacts. Some ideas can be found in following references.

Compatibility between bus/coach and other vehicles
The proposals that must be studied about the driver's workplace must go hand in hand with the study on the compatibility with other vehicles (industrial and cars). First it is needed to guarantee the security of the driver in the bus or in the coach against very different obstacles (at different heights and with different energy to be taken into account). On the other hand to guarantee the security of the occupants in the vehicle that could impact against the bus or the coach. It is important to pay attention to the results that will be obtained inside another European project called VC Compact, who are studying the compatibility between car and car and between car and truck.

Double-deck coaches (superstructure resistance)

The superstructure of the double-deck coaches must currently not be tested under rollover conditions. It is necessary to analyse how resistant the actual designs are and the economical and social impact of including those vehicles inside the requirements of regulations and directives on rollover.

That is especially important if the mass of the belted passengers is taken into account, because the increase of the energy to be absorbed during rollover increased with the number of passengers and the height of the centre of gravity.

Harmonised bus accident database

The performed statistical accident data collection showed a big difference between the capture of the data within the European countries. That indicates the necessity of an integrated database of the accidents that could take into account the same parameters in all the accidents and provide data for a good study on new necessities of research and/or requirements on buses and coaches.

Guidelines for using Numerical Techniques

The regulation 66R00 and the directive 2001/85 allow the approval by numerical methods. Nowadays there is a great variety of numerical techniques (as finite elements method or multi-body method) and a lot of commercial programs that permit to calculate the superstructure behaviour of a coach under rollover.

During this study, quasi-static and dynamic modelling methods have been used and validated. That work aims the necessity of carrying out some guidelines for using numerical techniques for approval, especially about how to validate the models.

Partial ejection out of the bus (side window / wind screen) should be avoided

The analysis of the real world accidents indicated that the partial or total ejection is a severe injury mechanism. The injury severity of the casualties is less if the bus is equipped with a seat restraint system and with laminated glasses. Besides, a side airbag especially developed for rollover movement could prevent from the ejection of occupants.

Contact load with side (window and structure) should be as low as possible

The numerical rollover simulations showed that the impact between dummy and side panel as well as the direct hit of the intruding structure on the dummy cause high load and therefore a big injury risk. That fact can be responded by either an avoidance of direct contact between dummy and side panel or by a soften impact behaviour. A calculation of relevant injury criteria would increase the safety standard especially for rollover.

Development of a rollover dummy is necessary to predict injury criteria

In-depth studies have shown that the most common body parts injured in a rollover, when no ejection occurs, are the head, the neck and the shoulder. This behaviour has been confirmed with the simulations performed with the validated Madymo models. These models have been used to study different rollover configuration to analyse the most frequent injury mechanism and to estimate the expected injury reduction using different restraint systems (2- and 3-point).

One of the conclusions of these studies is the fact that the current side impact dummies are not ready to assess the injuries suffered by the occupants of buses in case of rollover. Especially two important regions should be improved, the neck and the shoulder region (shoulder and clavicle as a whole).

The simulations showed that during rollover the neck is subject to combined loads namely lateral bending, lateral shear and torsion. Nowadays, there are no injury criteria that take into account these types of loads. The response of the shoulder in the current side impact dummies is not human like, the biofidelity of this region should be improved and an injury criterion to assess injury severity should be created too. Further research should be done in the field of rollover dummies and its associated injury criteria. The creation of a specific rollover dummy should be developed in parallel to the definition of new test procedures and the implementation of these procedures in the different regulations.

Further research on driver’s impact on accident avoidance

The in-depth study of the real world accident cases showed that a serious number of incidents was more or less negatively influenced by the action of the driver. Consequently the question whether the drivers know what to do or how to react in such a situation is certain appropriate. A further issue is the big range of technical standards of buses and coaches which demands different level of driver trainings.

Further research on possibilities for general rating of the passive safety

This suggestion is directed at a new definition of bus and coach safety. Since newer buses and coaches that meet the current Regulations and directives as well as a big fleet of older vehicles are on the road, the passengers of non scheduled transportation or municipal authorities responsible for scheduled transportation are more or less dependent on the available vehicles and so they have no special distinction features or identification possibilities of selecting a safe bus type.

An adapted classification similar to the star rating of (Euro) NCAP would definitely increase the safety level of future vehicles and could furthermore support the travel agencies to simplify the hire of a safer bus or coach (sales argument and demands). Although it is a long way off for realization it should be content of a further research.

CONCLUSIONS

This study was undertaken to identify the correlation between the current test approvals on passive safety for buses and coaches and the real-world accident incidents. Reasons for that claim were on the one hand the missing tendency of the fatality and injury rate in bus and coach accidents over the last years and on the other hand a missing research study on general bus and coach safety. Although several studies on individual topics of passive safety for buses and coaches exist which explain the single problems well, a comprehensive study which takes the interaction of the main safety relevant issues (frontal / rollover) under consideration is for the first time presented by this study.
For that purpose a statistical accident analysis was performed in a first step to gain basic knowledge on several usable information out from governmental databases. Despite the different ways of data collection within the European countries, it was possible to work out a general overall pattern. The results of this chapter were used to perform an in-depth accident analysis including detailed accident reconstructions and the compiling of a new defined bus and coach accident database.
Next step was the investigation on the main injury mechanisms according to this crash type. For that purpose this chapter was structured in different sections. The first part reports from different kinds of component tests which were performed to analyse the impact behaviour of e.g. interior components, seat systems and structural parts. These physical and material data were used in a further step to validate new created numerical simulation models for vehicles structures and occupant behaviour. Parameter studies, including type of occupant, type of vehicle and type of restraint system completed this experimental and analytical work.
Based on the knowledge gained within the accident analysis and the assessment of the injury mechanisms different test methods were elaborated and verified by means of different numerical simulation methods. For all proposed improvements and changes the current status of the test approvals formed the reference. The financial quantification of the increased safety features was done by a cost benefit analysis and showed a proper ratio for the additional charge.
Some recommendations for current European Regulations and Directives have been made based on the research performed within this study, essentially inside the Regulation 66R00 (Directive 2001/85/EC) and the Regulation 80R01. Some of them (related to 66 Regulation) have been taken into account by the Ad-Hoc Experts Group and are going to be included in the proposals that will modify the 66 Regulation in a near future.
The state of the technique and consequently the current regulations are still far away from the ones related to other types of transport (especially M1 vehicles). The results of this study can be considered as a first step towards new research, future designs and regulations to enhance the safety level of buses and coaches.
The realisation of these actions and the definition of new targets and future research represent a big challenge for both the scientists (technical, medical) and the industry and can only be solved by using interdisciplinary methods.

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TECHNICAL QUESTIONS OF BUS SAFETY BUMPERS

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ABSTRACT

This paper is based on accident statistics, theoretical considerations and physical tests of safety bumpers and their components. The statistical analysis shows the typical bus frontal collisions, their frequency and the possible advantage of the safety bumper in the typical collisions. The theoretical considerations try to outline the possible requirements of a safety bumper: deformation capability, energy absorption capability, strength requirements relating to the bus structure behind the safety bumper system, compatibility requirements, etc. When specifying these requirements all bus categories, all kind of buses (low floor and high decker, small and large, etc.) should be considered together with their special features. There are well-defined theoretical connections between the length of the deformation, the energy absorption of the bumper and the average deceleration of the bus having safety bumper in a frontal collision. This deceleration is an important figure when regulating safety belts and seat strength in buses. The tests, the results of which are discussed in the paper include: pendulum impact tests of components of safety bumper systems, static loading tests of these components and full scale frontal impact tests with complete buses against concrete wall. The differences between the results of static and dynamic tests – carried out on the same components – are shown and discussed. It is emphasized that the bumper cannot solve all the safety problems belonging to frontal collision of buses, but it may be a useful, effective tool in some cases (avoiding underrun type accidents, reducing the decelerations below a certain impact speed, etc.)

1. INTRODUCTION

Analysing bus accident statistics collected from different sources, different countries [1] in which somebody has been injured (bus occupants or other road user), some interesting figures may be cited:

- 30-50% of the accidents happened with vulnerable partners (pedestrian, bicyclist, motorcyclist, moped, etc.) No danger for the bus occupants.
- 30-50% with cars and vans, which are weaker than the bus but not, so defenceless as above. Danger mainly for the bus driver (and crew, if any) among the bus occupants.
- 10-30% with heavy vehicles and stable objects, which are very dangerous for the bus occupants.

The very wide range scatters are due to the different countries, different traffic circumstances, different data collecting methods, different systems in statistics, etc. The frontal collisions or run over type accidents among the total bus accidents are in the range of 55-65%.

Thinking about the front safety bumper of buses, the first question to be decided is: who or what should be protected by this bumper? The bus occupants (driver, crew, passengers) or the other road users (pedestrians, bicyclist, car occupants, etc.) or the important control systems of the bus (steering, brake, electric) or to reduce the damage (cost) of the bus and/or the other vehicles being involved in frontal collision of the bus. The theoretical answer on this question is that a multifunctional safety bumper would be the optimal solution.

Formerly (in the '70-s and '80-s) the bumpers of the buses were separate units on the front wall. They did not have any special safety function; they could not protect the front wall (or anything else) even in the case of a slight frontal impact, as it is shown on Figure 1.

Figure 1. Old style bus bumper as a separate unit

In the last fifteen years the separate bumpers disappeared and the bus bumper became an integrated part of the front wall having only aesthetic function. The background of this change is basically technological, today the whole front wall is made from fibreglass reinforced plastic as a complete unit. The bumper does not have any projection from the front wall, therefore it does not have any deformation capability without damaging the front wall. Example is given on Figure 2. This practice is generally used for all kind of buses (city bus, long-distance coach, etc.)

Figure 2. Integrated bumper, part of the front wall

Figure 3. Presumably safety bumper on buses.

On the other hand, there are a few buses, running in the everyday service presumed equipped with safety bumper. Figure 3. shows an example. The criteria of these safety bumpers – on the basis of which they were designed – are not known, only their position, shape and construction give us the feeling that they could have safety function, too. The lack of an international regulation results that there are no unified, clear requirements for bus safety bumpers, which means that the possible goals of these bumpers are not cleared up yet.

2. SAFETY BUMPER CONCEPTS

There are two major lines, on the basis of which the concept of the safety bumper can be formulated. Of course these two different concepts (their components) may be combined in the future practice, but theoretically it is better to discuss them separately.

2.1. Protecting the vulnerable road users, partners in a collision

In spite of the general considerations (full frontal impact) in this case the local properties and behaviour of the bumper have special importance. Three kind of vulnerable partners could be considered:

- Pedestrians. No energy absorption, no deformations, only the surface properties of the bumper are interesting (shape, radius of edges, surface hardness) and maybe its position (height above the road)
- Cyclists, motorcyclists. The bus bumper cannot protect essentially these road users. The bus itself – whether has a safety bumper or not – is a very aggressive „partner" for them.

Figure 4. Underrun type frontal collision

- Cars, small vans. One problem is to avoid the underrun type collisions with the safety bumper. Figure 4. gives an example: the underrun type collision with a small car (Trabant) was not too severe for the bus, but it was fatal for the car. The underrun type accident raises an other problem: the damage of the vital control systems located under the driver compartment (brake, steering, electric-electronic systems) The damage of these systems means that the driver can not control the further motion of the bus, even if the first collision with the car was not too severe, the second collision could be fatal.

An other question to be considered is the energy conditions of the bus-car frontal collision. Figure 5. shows the relations, how to estimate the equivalent energies and impact speeds in two cases:

- The bus hits a rigid wall
- A car hits the bus

The symbols are: **M** = mass of the bus; **m** = mass of a car; **c** = energy dissipation factor showing the energy absorbed by anything else expect the safety bumper.

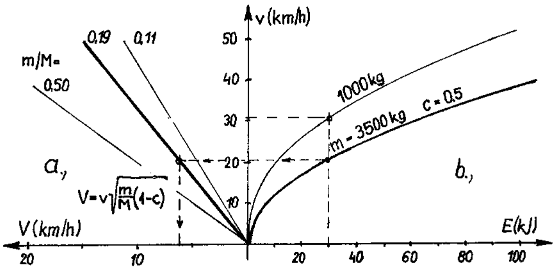

Figure 5. Equivalent impact speed (a) and impact energy (b)

Figure 5/b shows that a small car (1000 kg) with an impact speed of 30 km/h represents the same kinetic energy as a van (3500 kg) with 20 km/h impact speed. It may be read out from Figure 5/a that the equivalent impact speed of the bus producing the same kinetic energy – assuming a full frontal impact against a rigid wall – is about 6 km/h.

2.2. Protecting the bus and bus occupants.

The protection of the bus occupants has special importance when the bus collides a rigid wall, wall-like object or another heavy vehicle and the collision is full (not offset) For this case the working conditions of a safety bumper are shown on Figure 6. The safety bumper, as a complex system has three working ranges:

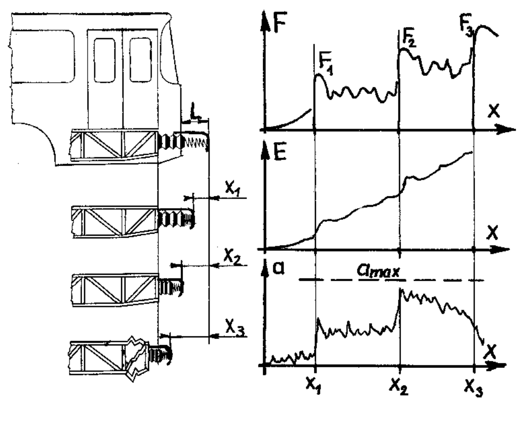

Figure 6. Working conditions of a safety bumper system

a) In the normal position (no impact, no load on the bumper) the bumper has a certain projection (L) from the front wall

b) The first working range (WR1) is a non-linear elastic deformation range having a maximum value $x_1 << L$ If the impact speed of the bus (v) is smaller than a limit value (v_1), no permanent deformation occurs, the bumper springs back, the impact energy is absorbed temporarily by the elastic deformation. This impact speed limit value could be rather low (e.g. $v_1 = 4$ km/h)

c) In the second working range (WR2) the bumper has a permanent, plastic deformation range ($x_1 < x \leq L$) If the impact speed is smaller than a limit value ($v_1 < v \leq v_2$) a permanent deformation will occur, but only in the bumper system, the front wall and other structural elements of the underframe structure remain intact. Practically it means that the bumper system has one or more structural elements, which absorb the impact energy while they are submitted to a certain plastic deformation. After the collision these elements are replaced by new ones and the whole bumper system is again in its normal position. The speed limit v_2 could be in the range of 15-18 km/h.

d) The third working range (WR3) is over the safety bumper capability, but it is strongly fitted to it. If the impact speed is higher than v_2 the safety bumper cannot absorb the impact energy, but in a certain speed range ($v_2 < v \leq v_3$) the impact should be controlled. For example the international regulation UN/ECE/Reg.80 describes the requirements for bus seats and seat anchorages in case of frontal impact with an impact speed of $v_3 = 30$ km/h. A certain deceleration pulse is assumed and described for seat tests for this standardized accident.

When designing and developing this kind of safety bumper system, a lot of technical parameters of the bus and the bumper shall be considered e.g. the mass, the impact speed, the allowed maximum deceleration or deceleration pulse, kinetic energy, etc. for the bus and the acceptable projection of the bumper, its energy absorbing capability, load bearing capacity, the main parameters of its working ranges, etc.

There are three basic criteria, on the basis of which these technical parameters shall be harmonized, fitted to each other in the three working ranges of the safety bumper system:

- Force criterion Figure 6. shows a typical force (F) – deformation (x) curve in the three working ranges (x_1, x_2, x_3) To assure the appropriate sequence of the working ranges during the frontal collision, the force in the whole lower working range shall be smaller than the force at the beginning of the next working range. (simply $F_1 < F_2 < F_3$) Otherwise the deformation in the next working range will start untimely, too early.

- Energy criterion. Every working range represents an impact speed limit which – considering the effective mass of the bus – determines a kinetic energy. This energy must be absorbed by the safety bumper, which means the bumper shall have this energy absorbing capability. The energy curve (E) on Figure 6 may be derived from the force curve (F) by integration.
- Deformation criterion. The working ranges of the bumper system belong to certain deformation ranges which are determined by two things: the energy absorbing capability and the maximum, allowable deceleration (deceleration pulse) It is interesting to mention that to day there is an administrative difficulty to develop and use safety bumper on buses. As it was shown above, to absorb energy, to limit the deceleration a certain amount of deformation (elastic and plastic together) is needed which means that the bumper requires a certain projection (L) from the front wall. To be effective this projection could be in the range of 250-350 mm. The total length of the bus – per definition – includes the bumpers too and every country, the national authorities determine length limitations for the large vehicles. Therefore to increase the projection of the bumper could mean to reduce the seat spacing (comfort of the passengers) or reduce the number of the seat rows (economy of the bus service) Therefore the bus operators and the manufacturers – without legislative force - are not enthusiastic for the safety bumper.

3. SAFETY BUMPER DEVELOPMENTS

3.2. Buses with experimental safety bumper

The development of a safety bumper system needs a lot of work: design considerations, laboratory tests and finally the validation of the whole effort by full-scale impact test of the bus. In the following some examples are shown about this development process. IKARUS Bus Manufacturing Co., working together with Research Institute of Automobile Industry produced and tested two buses with safety bumper systems [1]:

– Prototype of a 12 m long high decker long-distance tourist coach, type IK270 (see Figure 7.) The safety bumper concentrated to the partner protection: its surface was covered by a 40 mm thick square net plastic foam structure (see Figure 19.) The energy absorber was built from aluminium honeycomb (plate thickness 1,5 mm) filled up with plastic foam. Between the bumper structure and the underframe of the bus, two air springs were used, providing a 80 mm spring-way to decelerate the bus in total frontal collision. The air springs were non-linear elastic springs, so their energy absorption was temporally, they sprung back after the collision.

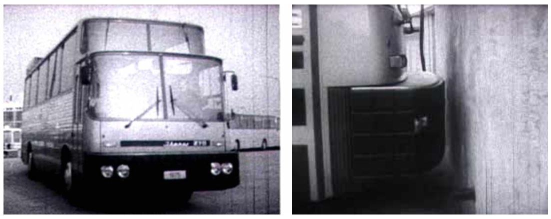

Figure 7. Long distance HD coach with safety bumper, before low speed impact test

– Serial version of a 11,4 m long IKARUS city bus – type IK 415 – with safety bumper, see Figure 8. The main goal of the bumper was to protect the bus occupants in total frontal collision.

The underrun protection was not a central issue in these two projects.

Figure 8. City bus with safety bumper, before impact test

3.2 Design considerations.

As an example, the design considerations and efforts will be shown with the city bus bumper development. The task was to develop a new safety bumper to an existing bus type (IK 415) which was already in serial production. The possible projection of the bumper from the front wall (L) was limited by the national total length limitation (12 m) and also the position, location was determined by the front wall structure and shape. The engineering lay out of the safety bumper may be seen on Figure 9. The goals were:

I. In WR1 no plastic deformation is allowed up to the impact speed v_1 = 4 km/h

II. In WR2 the energy is absorbed by plastic deformation of a removable part, the max. impact speed is v_2 = 8 km/h. No damage is allowed in the front wall structure.

III. In WR3 the plastic deformation of the underframe structure should be localized also to a changeable part, but the front wall damage is acceptable. The maximum impact speed v_3 = 30 km/h and the deceleration of the bus CG's shall be in the pulse given in ECE. Reg.80.

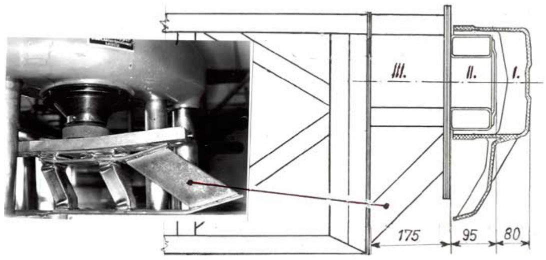

Figure 9. General layout of the safety bumper

To meat the three criteria described in para. 2.2. laboratory tests were needed to know something more about the structural elements, structures used in the safety bumper system.

3.3. Laboratory tests.

Many, different kind of laboratory tests have been carried out to get information about the behaviour of different structural elements. Figure 10. shows the force-deformation characteristics of non linear elastic rubber elements. The hysteresis in these rubber elements is rather small (15%) so their real energy absorbing capability is not significant. To the combined rubber structure shown on Figure 10. (three double elements) having deformation of 60 mm belongs a total energy of ≈ 15 kJ, while the really absorbed energy is around 2 kJ, the other 13 kJ belongs to the elastic spring return.

The underframe structures of the two buses equipped with safety bumper were built up from rectangular steel tubes. Therefore it is important to know the crash behaviour of these tubes. On the other hand these tubes may be used as components of energy absorber structures, too, therefore more hundreds of laboratory tests were carried out. Some examples are shown on Figure 11. where the crash characteristics, the buckling behaviours of rectangular steel tube (cross section 40x40x2 mm) and tube combinations are given. Some interesting conclusion of these curves:

- The buckling force (the first, highest peak of the curve) is almost linearly related to the area of cross sections of the tube combinations.

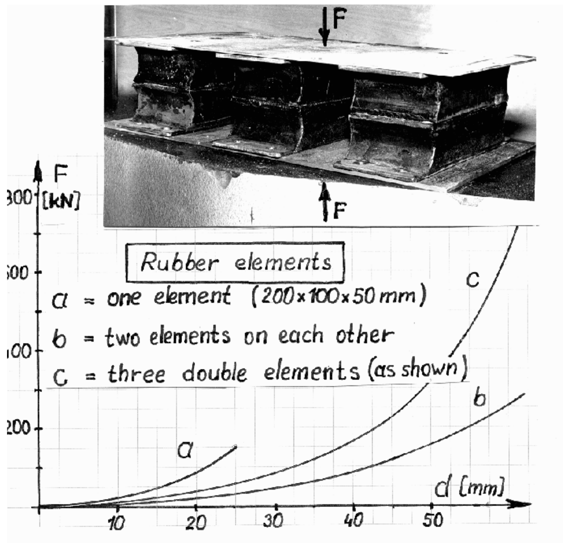

Figure 10. Force-deformation curves of rubber elements

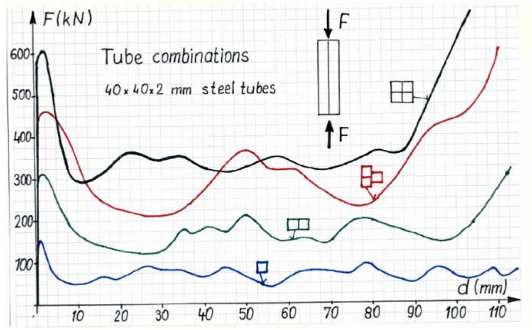

Figure 11. Force-deformation curves of rubber elements

- The hardening part of the curves (the last part, where the force is continuously increasing) does not show any close relation to the area of cross sections.
- The stable energy absorbing part of the curves (middle part between the first buckling and the hardening) there is a significant correlation between the area of the cross section and the absorbed energy.
- The buckling deformation process, the folding of the tubes, tube combinations are similar. Figure 12. shows the folding of a single tube, having a cross section of 40x40x2 mm and also the buckling of four tubes combination with the same cross section. Figure 13. gives two stages of the folding process of a two tubes combination.

Figure 12. Folding of a single tube and four tubes combination

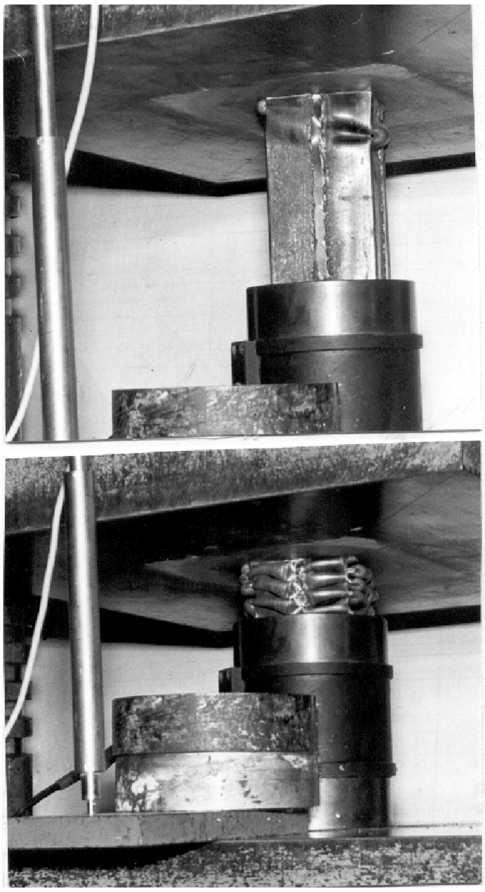

Figure 13. Folding process of a double tube combination

It is interesting to mention that the different arrangement of a tube combination (in which the area of the cross section is the same) may result significantly different buckling and energy absorbing behaviour. Figure 14. compares three different arrangements of the two tubes combination, in which the position of the tubes to each other are different. The significant differences are obvious.

There are two interesting phenomena which should be mentioned in relation to the folding buckling of tubular structures and should be considered when designing crashworthiness of bus frames, when calculating safety bumpers, energy absorbing elements built up from tubular structural elements. To meet the three basic criteria in the working ranges of the safety bumper discussed in para 2.2. these are essential phenomena:

- The compressed tubes may lose their stability on two ways, depending on the length of the tube [2] The "short" tubes have folding type buckling while on the "long" tubes rotational plastic hinges are formed. Between the "short" and the "long" ounces there is a transitional range in which both kind of loss of stability may occur accidentally. The "short" and "long" terms depend on the cross sectional parameters of the tubes (thickness area, ratio of the sides, etc.) Figure 15. gives an example measured on 40x40x2 mm tubes. The two curves represents two different force applications: one was through free end of tube (free deformation capability of the end of the tube) and the other through fixed end. (Welded plate on the end, no deformation capability)

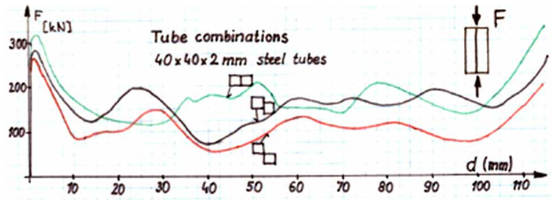

Figure 14. Force-deformation curves of different double tube arrangement

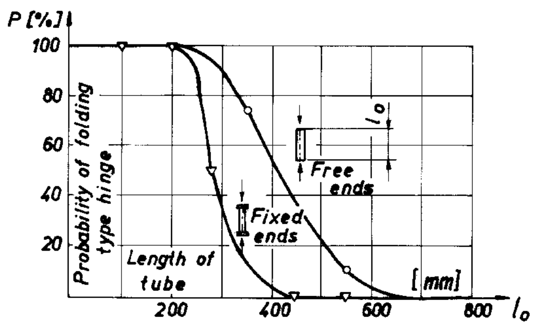

Figure 15. Probability of folding type buckling as function of tube length

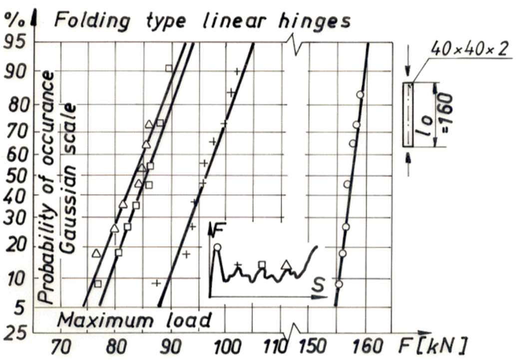

Figure 16. Distribution functions of force maximums.

- The folding process is random one, influenced by a lot of small accidental effects. All parameters of a force-deformation curve may be represented by a probability distribution function. As an example, Figure 16. shows the distribution functions of the local force peaks on the force-deformation curve. Ten 40x40x2 mm rectangular tubes were compressed with a length of 160 mm having free ends and their force deformation curves were analysed. The distribution of the first, second, third and fourth force peak are shown in Gaussian normal coordinate system. The mean value and the scatter of the distributions may be determined from these figures.

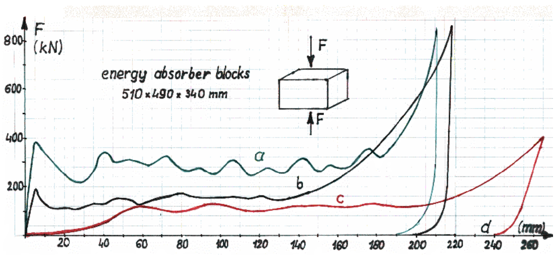

Figure 17. Force-deformation curves of energy absorber blocks

Another test series was carried out with special energy absorbers. Figure 17. shows the force-deformation curves of three energy absorber blocks (EAB) having the same dimensions (510x490x350 mm) but different construction:

a) Steel plate box (thickness: 0,5 mm) with a rectangular tube (40x40x2 mm) in every corner, welded to the plates with intermittent welds. The box was filled up with polyurethane foam (density: 80 kg/m^3) See Figure 18.
b) Spot welded steel plate honeycomb structure (plate thickness 0,5 mm 14 sub-boxes in the EAB) filled up with polyurethane foam (density: 50 kg/m^3)
c) Aluminium honeycomb structure (thickness: 1,5 mm) filled up with polyurethane foam (density: 50 kg/m^3). The surface of this EAB was covered by square net plastic foam, see Figure 19. This structure was used as the safety bumper of the prototype IK 270 long distance coach.

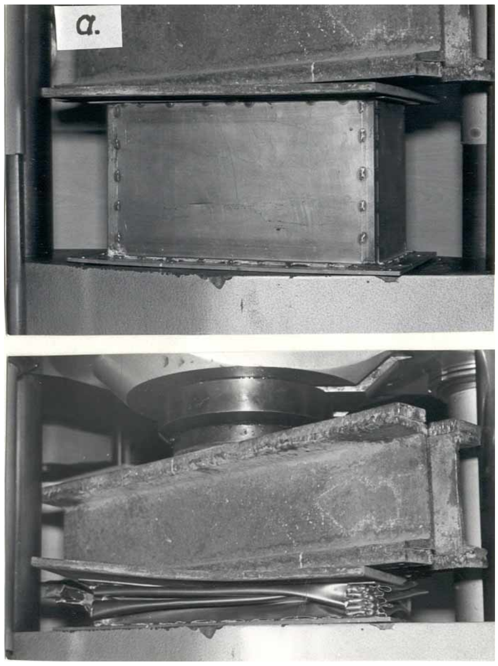

Figure 18. Test of a possible energy-absorbing block

Figure 19. Test of energy absorbing block of IK270 experimental coach

It is interesting to mention: in the case “a” the expected maximum force (loss of stability) was over 600 kN (Figure 12. shows that this value for one tube is more than 150 kN) Very likely the load distribution among the tubes was not equivalent, first two tubes on one side started the folding and after that the reminding two ones on the other side.

The test series was extended to compare the static and dynamic behaviour of energy absorbers. The dynamic tests were pendulum impact tests. Figure 20. compares the static and dynamic force-deformation curves of 40x40x2 mm steel rectangular tubes. Figure 21. shows similar diagrams for EAB type "b" (see above)

One of the main conclusions of these kinds of comparative tests is the hardening effect in the dynamic tests:

- The energy absorption, belonging to the same deformation (d) is higher in dynamic circumstances. In the case of steel tubes the ratio E_{dyn}/E_{st} is 1,2-1,3 but the honeycomb energy absorber showed a much higher ratio: 1,5-2,0
- On other hand this means that the same energy absorption belongs to smaller deformation in the dynamic tests.
- It was also observed that the dynamic tests produced cracks and fractures earlier, at smaller deformations than the static tests.

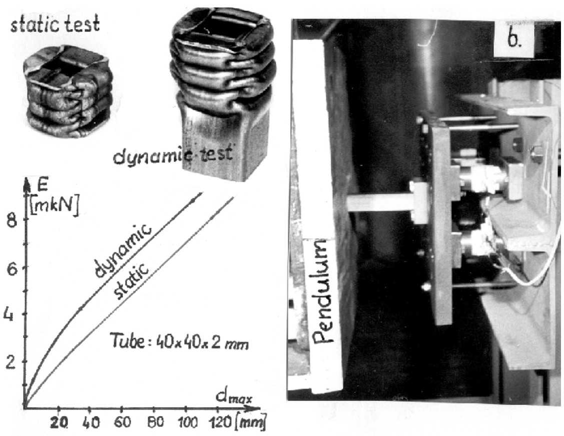

Figure 20. Static and dynamic behaviour of tubes

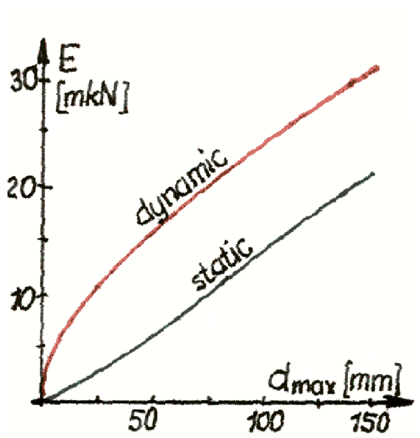

Figure 21. Static and dynamic behaviour of EAB

It is a key issue to have good, reliable correlation between the static and dynamic behaviour of the structural elements because in this case it is enough to make the much simpler and cheaper static tests in the early phase of the development.

3.4 Full scale impact tests

The validation of the development process (design, calculations, laboratory tests) could be a full-scale dynamic test, which may be carried out by a test bus impacting a rigid wall or the simulation of this impact e.g. by an appropriate pendulum test. Full-scale impact tests have been made with the type IKARUS 415 having the safety bumper, discussed in chapter 3.2. Figure 8. shows the test arrangement. According to the WR-s of the safety bumper four impact tests have been carried out, in WR1 and WR2 the real impact speeds were a little bit smaller than the planned ones: 3 km/h and 3,6 km/h (two tests, instead of 4 km/h) and 7 km/h (instead of 8 km/h) Figure 22. shows some of the measured parameters in these impact tests:

a) The total impact forces (two force transducers were used) as the function of time
b) The maximum values of impact forces and deceleration of the bus CG's as the function of the impact speed.

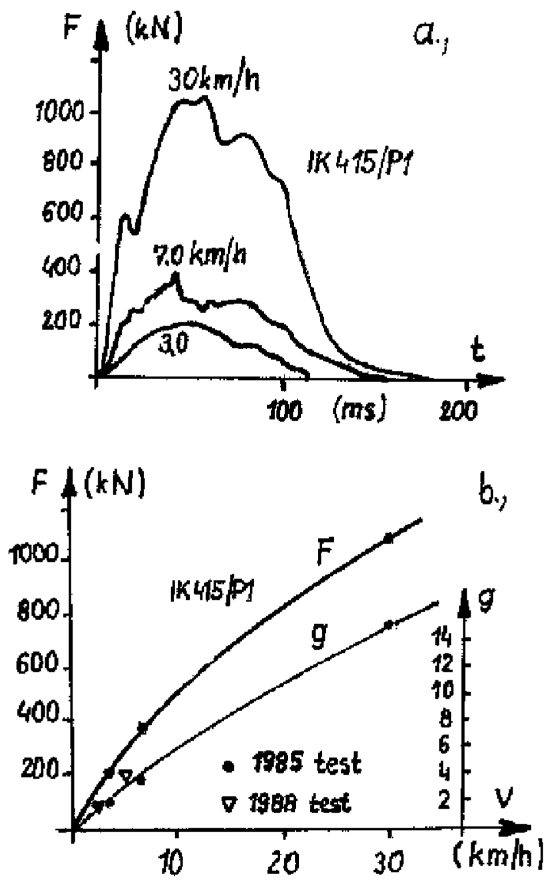

Figure 22. Measured values in frontal impact test.

The general evaluation of the test results, evaluation of the experimental safety bumper:

- In WR1 the safety bumper behaved well, there was no permanent, residual deformation after the two impact tests.
- In WR2 we had to realise a malfunction of the safety bumper system. Part II. (see Figure 9.) was too rigid compared to Part III. The requirement $F_1 < F_2$ has not been met, or in other words, Part III. started to work earlier than Part II., more exactly only Part III. worked and absorbed the energy, Part II. remained intact. The deformation of Part III. was a little bit bigger than it was planned for Part II., therefore the front wall (its panelling) was slightly damaged

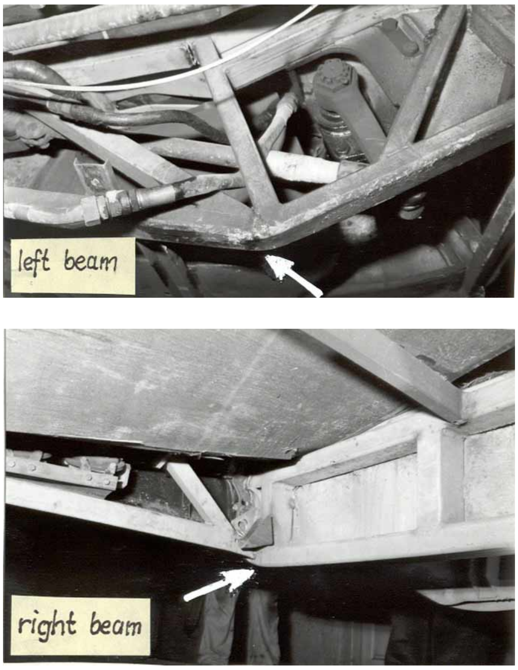

Figure 23. Deformation of the longitudinal beams of the underframe

- Replacing the deformed Part III. by a new, reinforced one, the last test checked the behaviour of the safety bumper system in WR3. To correct one mistake – as usually – creates a new mistake. Reinforcing Part III., now the underframe structure proved to be too weak, now the requirement $F_2 < F_3$ has not been met, so the longitudinal beams of the underframe structure endured undesirable deformations as it is shown on Figure 23. The two longitudinal beam had different construction because of the driver compartment (left side) and the staircase at the service door (right side) It is interesting to point out that the expected strength of these underframe beams were based on test result of tubes and tube combinations. But the phenomena discussed above (two possible ways of losing stability as the function of tube length, probability approach and the effect of the load distribution) were not recognized and considered yet.
- Structural parts, elements, components which are equivalent in respect to the normal service loads (linear stress-strain relationship, only elastic deformations) can behave completely different way when they are subjected to crash loads. Small local constructional differences can create essential differences in the initiation and working of plastic hinges, between their characteristics. The locality has much higher importance when designing structures for crash loads.

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[2] Matolcsy M. Crashworthiness of bus structures and rollover protection. Crashworthiness of Transportation Systems: Structural impact and Occupant protection. 1997 Kluwer Academic Publisher. Eds J.A.C. Ambrosio et al. p. 321-360.

THREE POINT SEAT BELTS ON COACHES - THE FIRST DECADE IN AUSTRALIA

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Abstract ID 05-0017

(Credit: Crashlab)

ABSTRACT

In July 1994 it became mandatory for Australian coaches to have three point seat belts in all passenger seats. This was the final part of a safety package that introduced improved rollover strength, improved emergency exits and other occupant protection initiatives. These measures followed two horrendous Australian bus crashes in 1989.

In Australia it is now common for groups, such as schools, to insist on coaches with three point seat belts for long trips.

The technical, operational and behavioural issues associated with three point seat belts on coaches are reviewed. Estimates of the effectiveness of these features in coach crashes are discussed.

INTRODUCTION

A serious downside with international harmonization of vehicle safety standards is that it too easily provides a “feel good” comfort zone for regulators and policy-makers. Sometimes it takes high media coverage of a tragedy to provide the political motivation to go beyond lowest common denominator (harmonization) and set a new world-leading benchmark in road user protection standards. Such a situation happened in Australia and led to the introduction of retracting three point seat belts on all passenger seats of new coaches.

Early in 1989 Australia was in the process of committing to international harmonization of coach occupant protection, with the intention of introducing a new Australian Design Rule based on ECE Regulation 80. In essence this required that coach seatbacks be strong enough and have energy absorbing properties to be able to ‘catch’ an occupant seated to the rear, and hence safely restrain them in a severe frontal impact.

However, late in 1989 two separate coach crashes occurred which resulted in 19 fatalities in the first crash and 35 in the second crash. Both were head-on crashes (the first with a heavy truck, the second between two coaches) in New South Wales on a two-lane national highway with a speed limit of 100km/h.

On-scene reviews by federal and state vehicle safety experts concluded that a regulation based on ECE 80 would not have been effective in these crashes.

Initial calculations indicated that nothing less than three point seat belts with a 20g crash force capability would offer adequate protection. This lead to the development of Australian Design Rule 68 (ADR 68) which became mandatory for all Australian coaches built from July 1994. Route service (urban) buses are exempt from ADR 68.

A Federal Office of Road Safety (FORS) Regulatory Impact Statement prepared in 1992 states that bus manufacturers and operators were critical of the proposed ADR and cited cost and weight penalties inherent in the package (FORS 1992). More than a decade later it is evident that those initial concerns were unfounded and acceptance of this rule by government, industry and road users is reportedly high.

In recent years consumer demands (particular school excursion/tour groups) have brought about a need for retro-fitting packages and/or phasing out of older coaches not fitted with three point seat belts.

Surprisingly, this Australian initiative has not been widely adopted internationally. Some researchers and regulators continue to debate the technical feasibility and consumer acceptance of three point seat belts on coaches, despite the use of such systems in Australia for more than 10 years

DYNAMIC TESTING OF PROTOTYPE SEATS AND SEAT BELTS

When ADR 68 was legislated coach seat manufacturers were initially reticent to conduct the necessary development work to produce seats which complied with the ADR. This had the potential to delay or abort the introduction of ADR 68 because, if complying seats were not available, then coach manufacturers and purchasers could legitimately have requested indefinite delays in the introduction of the rule.

To prevent this occurring, the New South Wales Roads & Traffic Authority (RTA) made an offer to coach seat manufacturers that there would be no fees for testing and assessment of their developmental prototype seats by the RTA Crashlab research and test facility. Initially manufacturers were reluctant to take up this offer.

Once the industry realised that the offer was for a limited time and that it involved considerable cost savings then successful collaborative development and test programs commenced. It wasn't long before enough seat manufacturers took up the offer to ensure the availability of ADR 68 seat and seat belt products in Australia.

Another widely held industry perception was that the more than doubling of the seat strength required would lead to significant increases in the weight of seats, which in turn, would reduce passenger capacity (FORS 1992). This would have affected the economics of coach travel.

Some of the early prototype seats did indeed get heavier. Manufacturers tried to meet the new standards by 'beefing up' (strengthening) the existing product with additional steel bracing.

These "beefed up" prototypes did not perform well in the testing process. Coach seat designers therefore decided to start with a 'clean sheet' and modern design tools. Taking this approach, seat manufacturers soon came up with seats which were more than twice as strong, weighed less and were not significantly more expensive (excluding the cost of seat belts) to produce than the original product.

Before ADR 68, Australian coach seats typically weighed 30 to 35 kg per pair. The latest Australian seats weigh as little as 25kg per pair with seat belts. For comparison, U.S. seats without seat belts are reportedly in the order of 40 kg per pair.

When ADR 68 was introduced there were approximately five coach seat manufacturers in Australia. For various reasons there are now two major suppliers of coach seats in Australia (McConnell and Styleride), with one of the bus manufacturers, Autobus, producing some of their own seats. Reportedly a very small number of bus seats are imported.

Besides new coaches, there is now also a relatively active retrofit program for ADR 68 seats in Australia.

Seat sales

Based on advice from the two major manufacturers of coach seats in Australia it is estimated that, since 1994, between 4,000 and 5,000 coaches have been fitted with ADR 68 seat and seat belt packages.

McGuire et al (2002) reported that, as at 2001, in New South Wales, 60% of registered buses (route service buses and long distance coaches) had been built before 1994 . This suggests that in 2001 about 40% of all registered coaches should have been fitted with ADR 68 seat and seat belt packages. Based on the turnover of the fleet, it is estimated that, currently, more than 60% of Australian coaches have ADR 68

Figure 1. Wall/floor mounted bus seat with integral three point seat belts (Styleride)

Figure 2. Floor mounted bus seat with integral three points seat belts (McConnell)

seat and seat belt packages. Importantly, new buses typically travel three times further each year than buses that are ten years or older (FORS 1992). Therefore the total annual kilometres for buses equipped with three point seat belts is likely to be much higher than 60% of all long-distance bus travel in Australia.

New coach purchases

The necessary lead time for the introduction of ADR 68 may have allowed some coach operators to order additional new buses for delivery before July 1994, so that they could avoid having the buses fitted with seat belts. There was reportedly a flurry of pre July 1994 coach building and a short term downturn in the manufacture of new buses following July 1994.

At around the same time the introduction of significantly cheaper air travel in Australia led to a further downturn in the requirement for new coaches. The competition from airlines also meant that some coach operators ceased business. As a result a cheap source of pre-July 1994 coaches came onto the Australian market. This may have resulted in a temporary setback in the uptake of coaches with three point seat belts.

CRASH PERFORMANCE

Fortunately, up to the time of writing, there has been no repeat of the catastrophic 1989 crashes in Australia.

Since 1994 there have been several serious bus crashes but no seat belt wearing occupant has been reported as receiving fatal or disabling injuries in any of these crashes. Paradoxically, the lack of serious coach crashes has resulted in a low level of in-depth investigation of coach crashes since 1994.

One reported crash to a coach occurred in a predominately frontal impact with the crash pulse assessed as equivalent to a 6g peak deceleration.

This coach was built in 1996 had 52 seats with three point seat belts. It was fully occupied and according to the tachograph was travelling at approximately 85 km/hr when it impacted a culvert. Post-crash inspection of the vehicle indicated that 47 of the 52 occupants were wearing their seat belts at the time of the crash. The two fatalities occurred from an unrestrained, sleeping relief driver who was thrown forward and his head struck the base of a seat. The second was a 12 year old child sleeping in the aisle. The remaining three unrestrained occupants had impacts with the seats ahead of them.

In another sideswipe crash between a truck and a coach, only one coach occupant received significant injury. In that case, the occupant (who was a tour guide) was unrestrained and was thrown forward into the footwell of the coach where their lower leg was partially amputated by intruding objects.

Further details of these and other crashes of coaches fitted with seat belts will be available in time for presentation at the ESV Conference in June 2005.

The Regulatory Impact Statement (RIS) that was prepared for ADR 68 did not attempt to estimate the effectiveness of three point seat belts on buses (FORS 1992). Instead the RIS indicated that the costs of building buses to ADR68 would be offset if the trauma cost were reduced by 20% to 41% (for a range of assumptions that have subsequently turned out to be too conservative).

Given the lack of severe coach crashes since 1994 and the lack of in-depth studies it is not possible to estimate the effectiveness of three point seat belts from Australian data. An estimate can, however, be made from US reports that have evaluated school bus crashes (Paine 2004, Peder 2002).

Crashes potentially influenced by lap/sash seat belts

Lap/sash seat belts could be expected to reduce injuries in frontal, side and rollover crashes of buses. Of crashes in which US school bus passengers were killed, 33% were frontal collisions and 26% were side collision (NHTSA 2002) . The number of rollovers (without prior frontal or side collision) is unknown but is no more than a few percent. It is therefore estimated that about 60% of all bus crashes in which passengers are injured could be expected to be influenced by lap/sash seat belts.

Effectiveness of three point seat belts in relevant crashes

NHTSA estimates that lap/sash seat belts would be 50% effective in reducing passenger fatalities in frontal crashes (NHTSA 2002). No estimate is given for other crash configurations but the authors note "properly used lap/shoulder belt systems have the potential to be effective in reducing fatalities and injuries in other (non-frontal) crashes. Belt systems are particularly effective in reducing ejection in rollover crashes" (NHTSA 2002).

Assuming these values also apply to Australian long distance coaches then three point seat belts could be expected to save about 30% of all fatal and serious injuries to coach occupants. This is within the range for cost effectiveness derived by FORS (1992) and based on very conservative assumptions about costs. This indicates that the lighter, cheaper seats that are now being installed in Australia are cost effective *on long-distance coaches*. This is regarded as a bonus because the original justification for ADR 68 was based, in part, on public expectation of higher standards of safety for coach passengers (FORS 1992).

These estimates are based on the assumption that all coach occupants wear their seat belts. Additionally it is noted that unrestrained occupants become a hazard to restrained occupants in severe crashes. Seat belt wearing rates are therefore an important factor in the continued success of the coach safety improvements.

SEAT BELT WEARING RATES

When the ADR 68 package was first introduced in Australia in 1994, the New South Wales Department of Transport (DOT), in conjunction with the RTA, committed to introduce programs to encourage high seat belt wearing rates, once coaches became available with seat belts.

It was envisaged that the seat belt wearing programs would be based on aircraft safety style briefings at the commencement of a journey.

There were already a number of activities which were prohibited on coach travel, and which, if breached, meant that a passenger would be offloaded, that is, they were essential conditions of travel. These included:-

- no alcohol consumption
- no smoking, etc.

It was planned to give a briefing where passengers were told that it was a condition of travel that the seat belt be kept fastened at all times, unless they were en route to a onboard rest room.

The planned briefings were to be standardized video presentations, where the development and supply of the videos was to be undertaken by the RTA. Where video facilities were not available on a coach (anticipated to be extremely rare for new coaches), then a standard briefing would be required to be read by the driver. As the bus regulator, the DOT had the authority to make it a condition of operation that these briefings were given at the commencement of a journey.

Unfortunately organisational changes within both departments during the 1990s meant that these commitments were not implemented. Furthermore we are not aware of any objective observational studies of the use of seat belts in coaches in normal charter or inter-city coach operations in Australia.

School bus trial

In a review of school bus safety in Queensland in 2001 by the School Transport Safety Task Force, the prospect of seat belts on school buses was examined.

Despite receiving evidence to the contrary, the Taskforce recommended a gradual introduction of seat belted buses into the school bus fleet.

In response to the recommendation, the Queensland government conducted a trial between January and June 2003. Seat belts were fitted to 12 school buses operating on long, steep and very steep routes in Queensland. An automatic mechanical/electronic seat belt wearing detection system was developed and fitted to six of the buses (Roper 2003). It had a switch in each seat belt buckle to determine whether the belt was fastened. Cabling was used from each individual buckle to data logging equipment at the rear of the bus.

Wearing rates varied widely from 14% to 89% with an average of 45%. Encouragement to wear the belts by teachers and parents had little effect on compliance. Teachers and parents interviewed and surveyed showed a tendency to significantly over-estimate wearing rates.

Overall, the study reported:-

- *The seat belt wearing rates recorded by this new system during the trial were generally low, even in areas of high encouragement. This indicates that some form of regulation is required to persuade students to wear the seat belts.*
- *The low wearing rates may also be the result of the design of the seats and belts, with many students reporting that they were uncomfortable and difficult to take on and off. This is compounded by the attempts of students to move around and talk to their peers around the high back seats.*
- *The misconceptions in the school community about seat belt wearing rates on the buses show that parents and schools are often unaware of what occurs on the school bus. This also indicates that there is a need for these groups to be more involved in the issue of school bus safety in order to increase wearing rates.*
- *Ultimately seat belts will not provide any safety benefits on school buses if they are not worn by the passengers. The results of this (Queensland) study show that the issue of seat belts on school*

buses is a complex one, requiring commitment from government, bus operators, schools, parents and students to achieve an effective compliance system.

Ultimately, the findings of this study identified many issues concerning the mandatory installation of seat belts on selected school buses.

Given the nature of the expert submissions made to the Queensland School Transport Safety Taskforce (that there are much more effective areas in which to spend money to improve safety of transport of children to and from school) this is probably a good outcome.

Wearing rates in Australian coaches

The information on wearing rates from those very few coach crashes that have been investigated shows a very wide disparity. The 1996 Tenterfield case showed a wearing rate of 47 out of 52(90%), whereas (unpublished) Police anecdotal records of several other coach crashes indicate wearing rates of less than 20%.

As stated earlier, no objective scientific observational studies have been conducted of seat belt wearing rates on coaches in Australia.

Three point seat belt equipped coaches were provided for delegate transportation to social functions at the 1996 ESV Conference in Australia, and ICrash 2002 in Australia. During these trips two of us observed wearing rates of well under 50%, despite the conference attendees being mostly experienced crash injury researchers.

It appears that the situation is very similar that of car seat belts in the mid-1960s - the technology has been sorted out but users are unaware of the severe injuries that can be sustained by (and due to) unrestrained occupants in crashes of relatively low severity.

There is clearly a need for an education program to encourage seat belt wearing by coach occupants.

CONCLUSIONS

During the research for this paper it became evident that registration and certification systems in Australia were no longer capable of easily identifying the individual or collective compliance of buses and coaches with individual design rules. What this means is that in any review of their relative safety, it is difficult to conduct comparative analysis of their performance.

In terms of monitoring the usage and effectiveness of seat belts on coaches in Australia, it became clear that there are no:-

- objective scientific observational studies of the usage of seat belts on coaches in normal use, and
- routine evaluations of the usage of seat belts on coaches involved in injury causing crashes in Australia.

However, it is likely that typical wearing rates are low (maybe 20%) and plans, developed in the early 1990s, to encourage coach occupants to wear seat belts should be resurrected. The need for such a program was notably absent from an RTA paper on heavy vehicle safety issued in 2003. The paper mentioned the widespread availability of seat belts on coaches but failed to acknowledge the potential problem of low wearing rates (RTA 2003).

Initial concerns about the cost and weight of seats fitted with three point seat belts have proved to be unfounded. The breakthrough was to abandon traditional seat designs and to develop new seats using modern engineering design tools. The resulting seats, fitted with seat belts, are no heavier (actually lighter in some cases) and not significantly more expensive than their predecessors. The importance of this outcome should not be underestimated - the potential benefits of seat belt restrained coach occupants has been achieved without increasing the cost of coach travel in Australia.

Australian coach seat suppliers report that typical ‘no frills’ ADR 68 seats with integrated seat belts but no accessories weigh approximately 25kg for a double, whilst a top of the range ADR 68 seat with accessories (recliner, footrest, trays etc.) weighs in at 30kg. This is significantly less than the 40kg typically reported for a double coach seat without seatbelts in North America.

The favourable weight and cost issues make it all the more surprising that this proven measure has not been more widely adopted elsewhere in the world The “not invented here” syndrome can lead to unfavourable outcomes for road safety.

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MOTOR COACH FIRES – ANALYSIS AND SUGGESTIONS FOR SAFETY ENHANCEMENT

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ABSTRACT

Motor coach fires are rare events – the resulting endangerment for the occupants exceeds that of passenger cars by far. A large number of persons is threatened by fire and smoke in an unfamiliar surrounding, panic reactions can occur. The clearance of the escape routes is limited and often blocked by luggage and personal belongings.

To find out more about the real life fire occurrence the German Federal Ministry of Transport, represented by the Federal Highway Research Institute entrusted DEKRA Accident Research to analyse bus fires and to work out a package of measures for safety improvement.

Current regulations for fire testing do not mirror all the requirements resulting from the findings won in the analyses of bus fires. A catalogue of alternative test procedures was compiled, geared to the procedures used in the railway industry to harmonise the requirements and to minimize the costs.

Additional proposals for effortless and cheap realisable measurements like smoke and fire monitoring of the passenger and engine compartment, another assortment of fire extinguishers, and passenger safety information cards have been added.

The complete research report [1] has been verified for practicability and effectiveness due to a series of full scale fire testing and an expert meeting.

Most analysed fires started in the engine compartment and spread there very fast. The extinguishing attempts of the bus drivers and persons passing by have been unsuccessful in the majority of the incidents. Nearly all fires started while the bus was driving, the fires were noticed in an advanced stadium by engine problems, malfunctions, or other drivers.

The presentation will give an overview of the suggested measures, the results of the analysis of the real world fire occurrence, and the full scale fire testing.

INTRODUCTION

Merely 190 motor coach fires have been reported to the German insurance companies in 1999 [2] – limited to this figure, improvements regarding the fire protection in motor coaches do not seem to be necessary. But on closer examination of the risk potential the endangerment of the persons affected by a motor coach fire is by far higher than that of those affected by a car fire. Without warning a large number of persons is exposed to a hazard in an unfamiliar surrounding. Design and utilisation lead to difficulties during the evacuation, particularly in combination with line-of-sight obstruction caused by smoke and panic reactions.

The endangerment resulting from a fire does not only stem from the flames but rather from the fires side effects like the smoke density and toxicology, and the heat release rate.

Within the DEKRA study the following motor coaches were analysed: Vehicles designed and built for long distance travel, equipped with special comfort features for seated passengers. Standing passengers are not transported by these vehicles. The coaches have more than 9 seats including the driver's seat [3]. These coaches are called "Reisebus" in Germany.

European rules and regulations handling motor coach fire protection are limited to small scale fire testing of single components. There are no tests concerning the emitted smoke or the fire growth rate. Constructional guidelines are limited to special components, e.g. regulating the fuel system integrity or safe distances of the exhaust system.

For a further improvement of the motor coach fire safety the DEKRA units "Accident Research" and "Fire and Arson Investigation" elaborated a catalogue of measures as part of the research report [1]. Besides new fire tests, mostly adapted from railroad regulations, a series of cheap and easy to implement organisationally measures have been listed.

MOTOR COACH FIRE OCCURRENCE

The selection of effective and realizable measurements for motor coach fire safety improvements requires an extensive knowledge of the real world fire occurrence. The official German on Road Traffic Accidents Statistic can only offer little information on that topic, fire is not listed at all [4].

The DEKRA evaluation is based on legal expert opinions, elaborated by own fire and accident reconstruction assessors. All together 55 written opinions from the period 1999 to 2004 could be collected and used for the evaluation.

Outside influences

Most of the analysed fires started while the engine was running. In 46 (84%) out of 55 cases the coach was driving, in three other cases (5.5%) the coach was stationary with the engine running. This is of great importance for the risk estimation – these are the states of operation occupants may be on board. The operation status while ignition is shown in Figure 1.

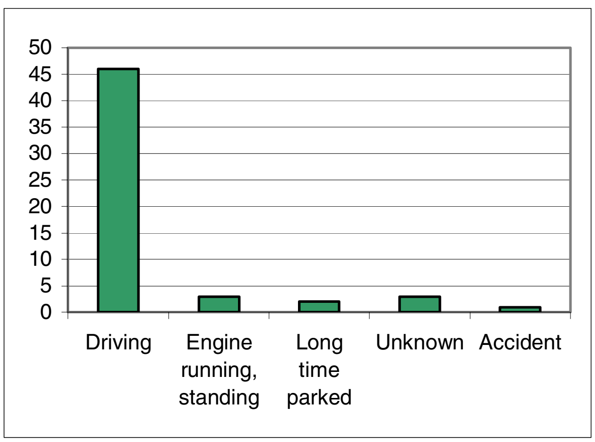

Figure 1 Operation status in the moment of ignition.

Taking a closer view to the locations the fires started, the urban roads and the rural roads are most frequently represented, followed by the Autobahns, Figure 2. Thus, it appears that the driven speed plays a subsidiary role. The engine temperature is of more importance. There was no ignition in the engine compartment while the engine was cold.

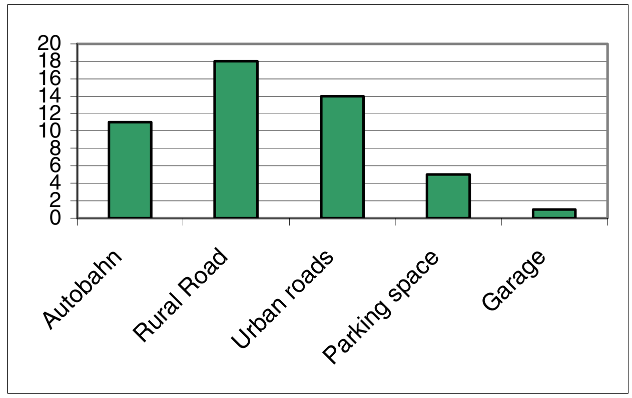

Figure 2 Location of ignition.

The date of first registration of the involved motor coaches was known in 42 (76%) cases. The distribution is shown in Table 1.

Table 1.
Distribution of the age of the analysed motor coaches.

Age distribution	Number
0 years	1
1 years	16
2 years	8
3 – 5 years	7
6 – 10 years	4
11 - 14 years	6

Cause of fire

For an effective countering of an ignition it is of importance to know the causes of fire and the components leading to the fire.

Leakages in the fuel- and oil-systems have been of relevance in 21 (38%) cases. With 11 (20%) cases each, mechanical damages and electric defects caused the ignition, Figure 3. It must be pointed out that the aforesaid causes are only one of the factors necessary for a combustion. Oil and fuel offer a combustible, mechanical and electric defects an ignition source Figure 4.

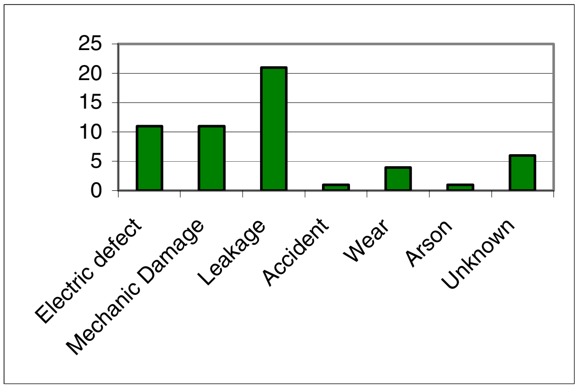

Figure 3 Causes of fire.

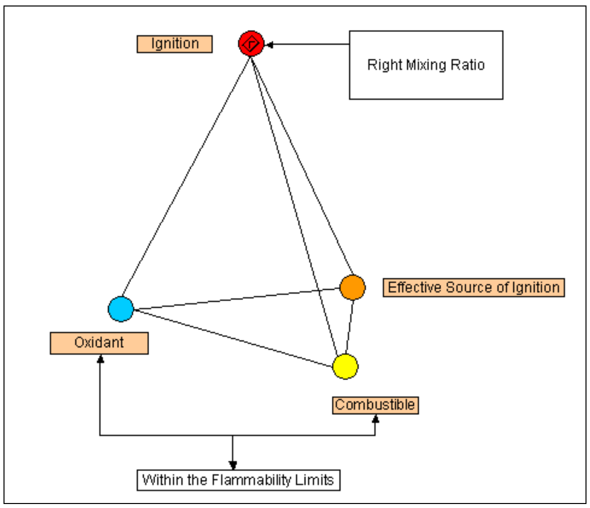

Figure 4 Ignition Tetrahedron based on Emmons

Documented sample cases

Exemplarily two cases are displayed here in the paper. In the first an electric defect of a hand-dryer led to a fire in a toilet of a parked coach. The plastic body of the dryer burnt, emitting large amounts of smoke. Moreover the plastic dropped on the floor burning. The close locking of the toilet's door cut off the oxygen supply, the fire died down itself, Figure 5, and Figure 6.

Figure 5 Melted hand-dryer and smoke damage.

Figure 6 Toilet door with smoke-marks.

The second case is a well documented motor coach fire, starting from the engine compartment, leading to a total loss of the vehicle.

The fire was detected when the front door opened while driving on the Autobahn. After evacuating the coach, the driver tried to extinguish the fire, using the coaches fire extinguisher and two additional ones, made available by passing by truck drivers. Because of a lack of training in fire extinguisher handling the driver did not manage to put the fire out Figure 7.

Figure 7 Driver's attempts to extinguish the fire [5].

After turning away the attached luggage box, the engine fire spread very fast, the occupant compartment is already filled with smoke. Nevertheless some passengers re-entered the coach to get out personal belongings, Figure 8, Figure 9.

Figure 8 Engine fire after turning away the luggage box [5].

Figure 9 Passengers re-entering the coach [5].

After about 10 minutes the rear part of the occupant's compartment is on fire, the whole compartment is filled with thick smoke, Figure 10. Less than one minute later a flashover sets the complete coach on fire, Figure 11. The thermal radiation heats up the luggage stored next to the bus, leading to a pyrolysis, Figure 12, and a self ignition, Figure 13.

Figure 10 Fast fire spread, the complete coach is filled with thick smoke after about 10 minutes [5].

Figure 11 Flashover [5].

Figure 12 Pyrolysis of the luggage stored besides the bus [5].

Figure 13 Self ignition of the luggage [5].

When the fire brigade arrived about 16 minutes after the detection of the fire, neither the coach nor the luggage could be rescued, Figure 14. The Autobahn has not been closed before the fire brigade arrived. The occupants have additionally been endangered by the running traffic.

Figure 14 Arriving of the fire brigade after about 16 minutes [5].

ESTABLISHED LAW AND LEGISLATION

Currently the German national regulations regarding the motor coach fire safety are limited to the requirement of a single 6 kg dry powder fire extinguisher for long distance motor coaches and a second extinguisher for double deck busses [6]. Additional demands are made on European basis.

Regulation 95/28/EC prescribes three different small scale fire tests for motor coach internal fittings. This directive applies to the burning behaviour (ignitability, burning rate, and melting behaviour) of interior materials used in vehicles carrying more than 22 passengers, not being designed for standing passengers and urban use (city busses).

The interior materials of the passenger compartment, used in the vehicle to be type-approved, shall undergo one or more of the following tests (if necessary the composite materials, as used in the vehicle, are to be tested):

1. Test to determine the horizontal burning rate of materials, similar to FMVSS 302 [8].
2. Test to determine the melting behaviour of materials: the sample is placed in a horizontal position and is exposed to an electric radiator. A receptacle is positioned under the specimen to collect the resultant drops. Some cotton wool is put in this receptacle in order to verify if any drop is flaming.
3. Test to determine the vertical burning rate of materials: the sample is held in a vertical position, exposed to a flame. Measured is the speed of propagation of the flame over the material.

The tests 2 and 3 are only used for motor coach fire safety testing. This makes the procedures expensive and reduces the number of testing facilities to be considered. Moreover the tests do not really mirror the entire real life fire occurrence. Interactions of different components during the combustion and the smoke emission are not tested at all.

Constructional guidelines are given in regulation 2001/85/EC [9] applying to every single deck, double deck, rigid or articulated vehicle of category M2 or M3 (as defined in Annex II, Part A, of Council Directive 70/156/EEC [10]). Herein a partition of heat-resistant material between the engine compartment or any other source of heat is approved. Electrical cables shall be located in a manner that no part can make contact with any fuel line or any part of the exhaust system, or be subjected to excessive heat, unless suitable special insulation and protection is provided. Additional requirements concering the battery accessability and placement are formulated. Spaces for a fire extinguisher and a first aid kid are to be provided.

Many similar requirements are given by ECE R 36 [11]. Extra are rules for the mounting of fuel system components and an electric emergency switch to cut off the energy supply.

DEKRA DEMANDS

Based on the findings won during the research DEKRA worked out a catalogue of demands to improve the fire safety of long distance motor coaches and to further limit the risk of the driver and the passengers. Beside new fire test procedures, primarily adopted from the railroad standards, easy realisable and cheap improvements have been taken up in the catalogue.

Fire detection

With the most fires starting in the engine compartment an automatic fire detection and alarm device should be mandatory. In fact, this is very important within the scope that most fires have been detected in a very late state. An early detection is important to extend the time for an evacuation and to increase the chance for an effective fire fighting by laities. Suggested is a system working with thermo detectors.

Automatic fire suppression systems are very effective and already offered as an extra for many coach types Figure 1. But they are still expensive and weighty. DEKRA favours the installation of such systems, but they should not be mandatory.

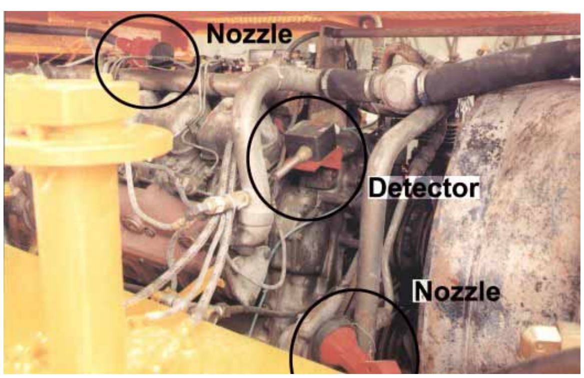

Figure 15 Automatic fire suppression system [12].

An early detection is also of importance in the passenger compartment. DEKRA suggests the use of optic smoke detectors. By placing them at the ceiling and in the toilet's cab a smoke development can be noticed in an early stadium. This is relevant during rides at night with the passengers sleeping and while driving without passengers on board. The cross-linking of the fire alarm system with that of the burglar alarm does also protect the parked bus.

Fire extinguishers

Actually there is no uniform regulation for fire extinguisher needs in motor coaches in Europe. If there are any requirements they are based on national law. E.g. the German Road Traffic Regulations [6] demand a 6 kg dry powder fire extinguisher. This is based on a redeemed German DIN standard [13], already replaced by the European Standard EN 3 [14]. A 6 kg type does no longer exist in that standard.

DEKRA suggests a dry powder extinguisher with a minimum of at least 6 extinguishing agent units nearby the driver's seat and a foam fire extinguisher with at least 4 extinguishing agent units (Calculated on basis of [14] and [15]). All together 12 extinguishing agent units are necessary.

Dry powder is the best extinguishing agent for engine fires. Foam is the better choice for the passenger compartment. Foam is, what most people expect to be a fire extinguisher's filling. The use of foam does not lead to a powder cloud (line of sight obstruction and difficulties of breathing), and the consequences of a misuse are not that serious.

An additional foam fire extinguisher with at least 4 extinguishing agent units is suggested for each stairway of double deck coaches.

Battery and electric components information

Interviews of fire fighters showed that they need a clearly visible pictogram on the battery-box and a map showing the locations of potentially existing extra batteries, of the emergency switch and the laying of the main wires. This can help to prevent an electric ignition after e.g. an accident.

Passenger information

The passengers should be informed about the safety features of the bus before starting the tour. Beside the location of the emergency exits and their handling, information about the places of the fire extinguishers and first aid kit, the safe storage of the luggage and the regulations concerning seat belt wearing should be covered. Additional proper instructions about the right behaviour in emergency situations are essential.

Passenger information cards, as used in the aviation sector, are very useful for that. For the design, pictograms should be used – that way language problems can be circumvented.

Driver education

The analysis of the real world fire occurrence and the questioning of persons who have been involved in bus fires have shown that many drivers are not sufficiently trained in handling a fire extinguisher.

Most passengers injured during the analysed fires have already been brought out of the bus, before they re-entered it to get out personal belongings. Hereby they sustained smoke intoxications. It is the bus driver's job to evacuate the vehicle completely and lead the passengers to a safe place. He additionally has to avert that anybody is re-entering the bus, expect for live saving measurements. The right behaviour in case of a fire needs to be an important point in the drivers education.

Design features

With most fires starting in the engine compartment this is the area with the largest potential for fire prevention and limitation of the fire spread.

The use of porous materials for insulation should be limited. Also coated materials should be banned – the coating can be damaged and loosing its function. Even if the porous material is non flammable it works like a candlewick by carrying the combustible mixture of oil, soot and other dirt.

The separation of the passenger compartment and the engine compartment, the firewall, should withstand a developed engine fire for a couple of minutes and offer enough resistance against heat transfer ().

Critical accumulations of spilling fluids need to be easily detected during the regular checks by the driver and the garage.

The battery box needs to be an own unit separated to all other areas, only accessible from outside the bus. It needs to be resistant against battery acid.

Fire testing

The existing regulations for fire testing of materials used in motor coaches do not mirror the real life fire occurrence. The emitted smoke is not tested at all, the tests are limited to single materials, the cross-influences of materials used in larger components like the seats are not analysed.

The number of standardised fire tests does not require the "invention" of a new one for motor coaches. Very useful tests can be adopted from the railway sector. It is also advantageous that many companies supply parts and components for both, railway and coach industries.

The listing of the recommended tests would go beyond the scope of that paper. Exemplified with the UIC paper cushion test [16] the suggestion for seat testing are described. Within that test, a standardized paper cushion made of newsprint is placed on the seat cushion at the edge with the backrest. After ignition at all four corners the burning behaviour is observed. Among other criteria, the fire must have self extinguished after at least ten minutes to pass the test.

DEKRA FIRE TESTING

To validate the suggested tests, to check the fire performance of actual offered components, and to get further information about the temperatures and variation in time during the fire spread DEKRA carried out some fire tests.

For the tests an old coach was equipped with different actual seats and an actual floor and wall lining. In the first step an on-seat-paper-cushion test was carried out. The seat passed that test explicitly. The first smoke detector, attached to the ceiling nearby the rear exit, set off after about two minutes, immediately after the seat started to emit smoke. The CO-concentration arose to 44 ppm in the fifth minute before declining again (AEGL-2 limit: 420 ppm, AEGL = Acute Exposure Guidline Levels, [17]). The HCN concentration reached the ETW-limit of 5 ppm but did not exceed it (ETW = Einsatz Toleranz Wert [18]). Both measuring points were located nearby the seat, an endangerment for occupants has not existed at any time, Figure 16 and Figure 17.

Figure 16 Configuration of test 1 with paper cushion.

Figure 17 Burnt down paper cushion.

In the second test a paper cushion was placed under a seat. Also that test was passed by the seat explicitly. The thermal load of the floor-lining led to an enormous smoke emission. The CO-concentration climbed to uncritical 84 ppm, HCN could not be detected. The smoke emitted by the floor lining would have led to line-of-sight obstructions and irritations of the respiratory tract, Figure 18 and Figure 19.

Figure 18 Configuration of test 2 with paper cushion.

Figure 19 Burning paper cushion.

In a third test the seat was set on fire by using half a litre of fuel. The smoke alarm set off after just 16 seconds. The luggage rack started to burn with burning drops falling on the floor, igniting that. It took 44 seconds until the smoke filled the complete bus down to the upper edge of the backrests. The complete passenger compartment was filled with smoke after 160 seconds. A self-rescue was impossible after 84 seconds.

The coach was completely closed during the first 530 seconds after ignition to get further information about the influence of air ventilation. The flash-over started 70 seconds after opening the doors.

The maximal temperature was measured in the moment of the flash-over. The temperature at the ceiling reached nearly 1,000°C, Figure 20 to Figure 23.

Figure 20 Seat set on fire with 0,5l of fuel (t = 10s).

Figure 21 Smoke-filled coach after opening the doors in second 530.

Figure 22 Flash-over and start of fire fighting (t = 600s).

Figure 23 Breaking of the side windows during the flash-over (t = 600s).

The very high level of fire performance of the tested seats was obvious after that test. The seats located in front of the ignited one had only received little fire damage. That status could be documented by starting the fire extinguishing immediately after the flash-over, Figure 24.

Figure 24 Seat row in front of the ignited seat. Covering removed by the fire brigade.

CONCLUSIONS AND DEMANDS

Motor coach travelling is with just 0.14 killed per milliard person kilometres one of the safest ways to move from A to B. But that does not mean that no more improvements for coach safety are required. Within a research-project of the German Federal Ministry of Transport, represented by the Federal Highway Research Institute, DEKRA Accident Research was entrusted to work out a catalogue of demands to improve the fire safety of motor coaches. Based on the real world fire occurrence a list of measures, easy and cheap to implement, was developed. Additionally a catalogue of fire tests was drawn up.

Good progress can be made by simple organisational measures. A better training of the drivers, an optimised fire extinguisher concept (dry powder for the engine, foam for the passenger compartment), rescue service information about the battery location, emergency switch and wiring, and passenger information cards are most promising.

With most fires starting in the engine compartment, mostly noticed only in a late stadium of fire propagation by the driver, an automatic detection is of importance. DEKRA suggests a thermal fire detection system for the engine compartment and an optic system for the passenger compartment.

Design features need to prevent the fire spread from one compartment to the other. Especially the sealing of the engine compartment to the passenger compartment needs to be mentioned here. The battery should be located in a separate box, only accessible from outside the bus and resistant against battery acid.

In the long term a replacement of the currently mandatory fire tests is advantageous. Yet neither the smoke nor cross influences of different materials are observed. By adapting the test procedures of the railway industries also extra costs can be saved by not having a special coach procedure.

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